17 FARALLON DE PAJAROS

17.1 Introduction

Farallon de Pajaros is the most northerly of the 14 islands of the Commonwealth of the Northern Mariana Islands (CNMI) and is located 67 km northwest of Maug at 20°33′ N and 144°54′ E. Farallon de Pajaros, which translates from Spanish to Isle of the Birds, is also known as Uracas from the Spanish word *urraca* meaning magpie. This island is ~ 1.6 km wide and 1.8 km long with a land area of 2.25 km^2, making it the second smallest island in the CNMI (Fig. 17.1a). The part of Farallon de Pajaros that is visible above the ocean is the small, aerial portion of a large volcano, the base of which lies in depths > 2000 m and is some 15–20 km in diameter. The rim of this volcano's crater is the highest point on this island with an elevation of 360 m, and it is surrounded by steeply sloping sides that lead to precipitous cliffs around much of this island's coast (Fig. 1717.1b).

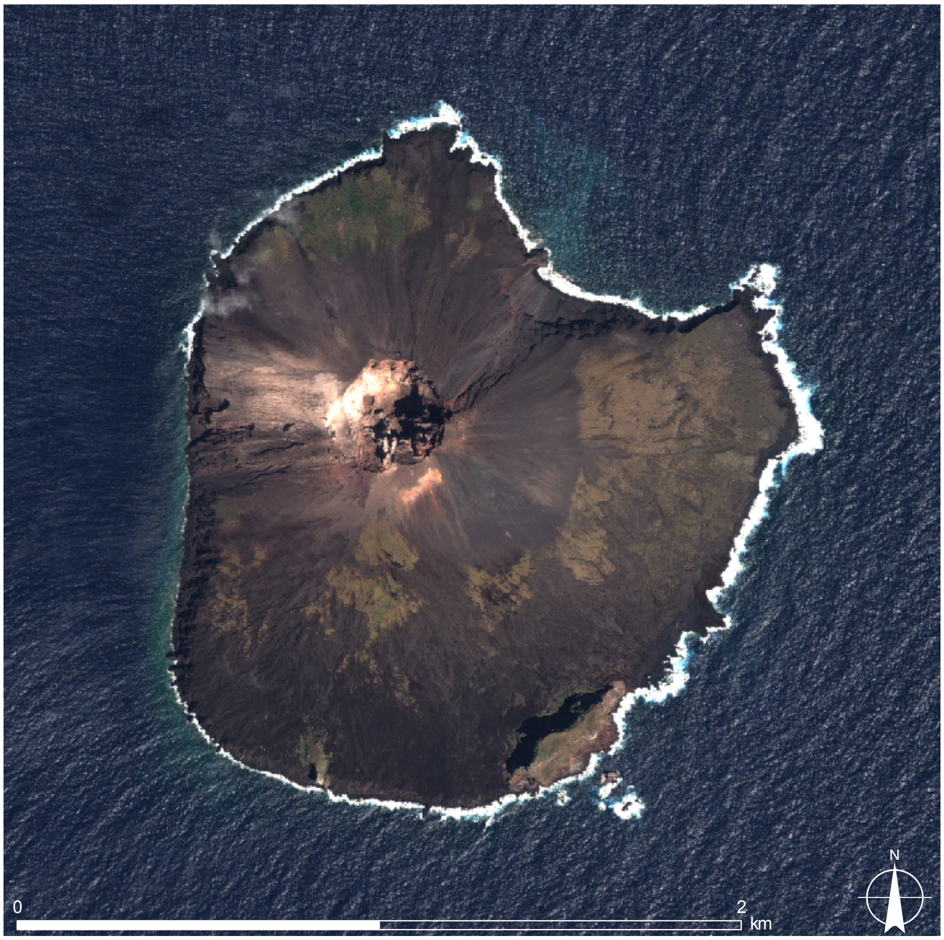


Figure 17.1a. Satellite image of Farallon de Pajaros (© 2004 DigitalGlobe Inc. All rights reserved).

Figure 17.1b. The west side of Farallon de Pajaros as seen from the NOAA Ship *Hi`ialakai* in June 2007. *NOAA photo by Emily Hirsch*

17.1.1 History and Demographics

Farallon de Pajaros is, and has probably always been, permanently uninhabited because of its inhospitable terrain, frequent volcanic activity, small size, and, now, protected status. The political history of Farallon de Pajaros is that of the CNMI as a whole, which has been described in more detail in Chapter 1: "Introduction" and Chapter 8: "Saipan," Section 8.1: "Introduction." In 1909, while under administration by Germany, Farallon de Pajaros (along with Agrihan, Asuncion, Guguan, Maug, Farallon de Medinilla, and Sarigan) was leased to the Pagan Gesellschaft for exploitation of bird plumage for a period of 3 years (Spennemann 1999b). During this time Japanese bird catchers were employed on these islands and may have been temporarily resident on Farallon de Pajaros.

17.1.2 Geography

Farallon de Pajaros, like other islands in the northern Mariana Arc, is a high volcanic island. It is a steeply sloping, recently active volcano with most of its surface covered with lava, cinders, and ash (Figs. 17.1.2a and b). At some point during the volcano's history, flank fissures have fed lava flows, creating platforms along the coast of Farallon de Pajaros (Siebert and Simkin 2002–). This island's summit is a central cone within a small caldera that cuts into an older edifice (Siebert and Simkin 2002–).

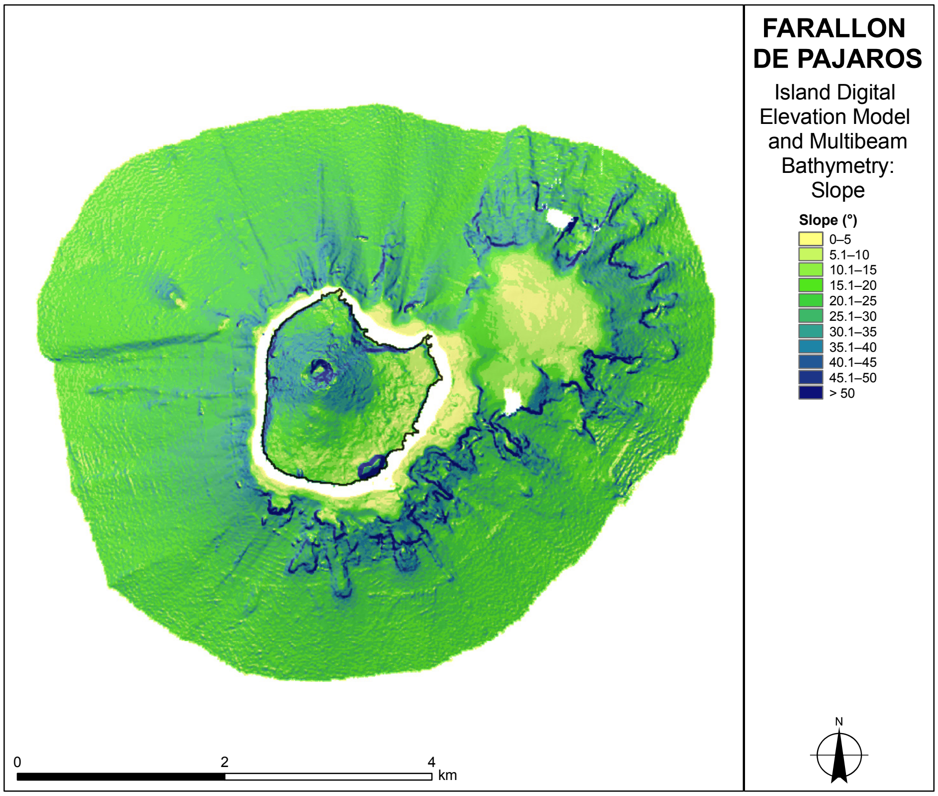


Figure 17.1.2a. Combined slope map using the digital elevation model and multibeam bathymetric data for Farallon de Pajaros (grid cell size: 10 m).

Farallon de Pajaros is considered one of the most volcanically active islands of the CNMI with at least 15 eruptions since 1864. Frequent eruptions during the 19th century led it to be known as the "Lighthouse of the Pacific." Eruptive activity was recorded throughout the 1940s, 1950s, and 1960s. The last known eruption was recorded in 1967, and a team of volcanologists, during a recent visit to this island, reported fumaroles continuing to emit gas and sulfur visible within the crater (University of California San Diego 2009). The Makhanas Seamount, which is located at 10 km southwest of Farallon de Pajaros, and Ahyi Seamount, which lies 18 km southeast of this island, are also still active (Siebert and Simkin 2002–).

Figure 17.1.2b. A view of the northwest side of Farallon de Pajaros, showing sulfurous rocks and ash slopes. *NOAA photo by Russell Moffitt*

The volcanic material that is widespread across Farallon de Pajaros supports little in the way of vascular plants. This island is largely unvegetated, although older rocks support thin, grassy vegetation (Fig. 17.1.2c). Two large outcropping rocks on the south coast of this island are vegetated (Fig. 17.1a). Small areas of vegetation include sedge communities and succulent communities on coastal rock (Mueller-Dombois and Fosberg 1998). Coconut and other trees planted by Georg Fritz, the first German administrator, during his visit to this island in 1901, apparently could not subsist, as photographs taken some 50 years later show no evidence of any trees on this island (Mueller-Dombois and Fosberg 1998). Landslides on this island's steep slopes have been observed during biennial Mariana Archipelago Reef Assessment and Monitoring Program (MARAMP) surveys.

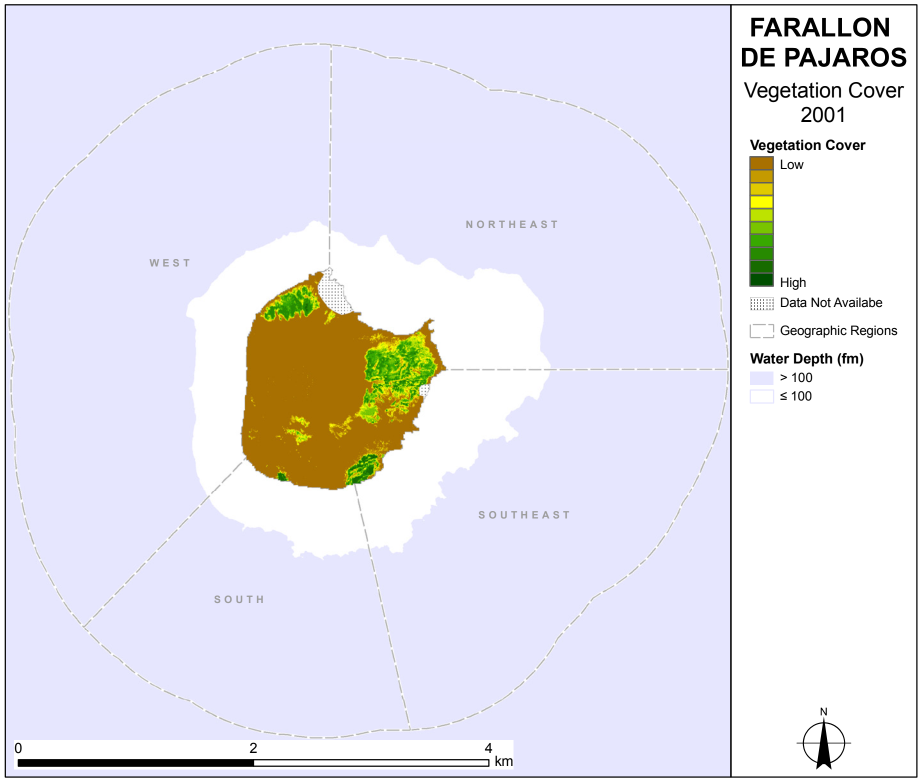


Figure 17.1.2c. Vegetation cover on Farallon de Pajaros, derived using the Normalized Difference Vegetation Index from a satellite image (grid cell size: 4 m; IKONOS Carterra Geo Data, 2001). Hatched lines display areas where data are not available because cloud cover obscures the satellite image.

17.1.3 Environmental Issues on Farallon de Pajaros

Because of its isolated location and lack of inhabitants, Farallon de Pajaros likely has few anthropogenic pressures. Fishing activity within the CNMI tends to be focused around the southern islands of the Mariana Archipelago, with multi-day fishing trips focusing on the islands and banks south of Guguan (Western Pacific Fishery Management Council 2009).

This island is part of a protected wildlife reserve, the Uracas Island Preserve, established in 1985 under an amendment of Article XIV of the CNMI Constitution and managed by the CNMI Division of Fish and Wildlife. This legislation states that Farallon de Pajaros and other islands "shall be maintained as uninhabited places and used only for the preservation and protection of natural resources" (CNMI Constitution). This island is preserved as a habitat for birds, wildlife, and plants. The Uracas Island Preserve protects 20 species of birds, including the red-tailed and white-tailed tropicbirds (*Phaethon rubricauda* and *P. lepturus*), 3 species of booby (masked, *Sula dactylatra*; red-footed, *S. sula*; and brown, *S. leucogaster*), and the endangered Micronesian megapode (*Megapodius laperouse*), which is locally common, breeds on this island, and is listed both Federally as an endangered species (U.S. Fish and Wildlife Service) and locally as a threatened or endangered species (Berger et al. 2005). Unlike on many other islands of the CNMI, no feral goats have been reported on Farallon de Pajaros (Pacific Protected Areas Database).

Farallon de Pajaros was included within the Marianas Trench Marine National Monument, formed by presidential proclamation in January 2009. This Marine National Monument includes a Trench Unit, an Islands Unit, and a Vents Unit. The Islands Unit includes the waters and submerged lands of the islands of Asuncion, Maug, and Farallon de Pajaros.

17.2 Survey Effort

Biological, physical, and chemical observations collected under MARAMP have documented the conditions and processes influencing coral reef ecosystems around the island of Farallon de Pajaros since 2003. The spatial reach and time frame of these survey efforts are discussed in this section. The disparate areas around this island often are exposed to different environmental conditions. To aid discussions of spatial patterns of ecological and oceanographic observations that appear throughout this chapter, 4 geographic regions around Farallon de Pajaros are delineated in Figure 17.2a; wave exposure and breaks in survey locations were considered when defining these geographic regions. This figure also displays the locations of the Rapid Ecological Assessment (REA) and towed-diver surveys conducted around this island. Potential reef habitat is represented by a 100-fm contour shown in white on this map.

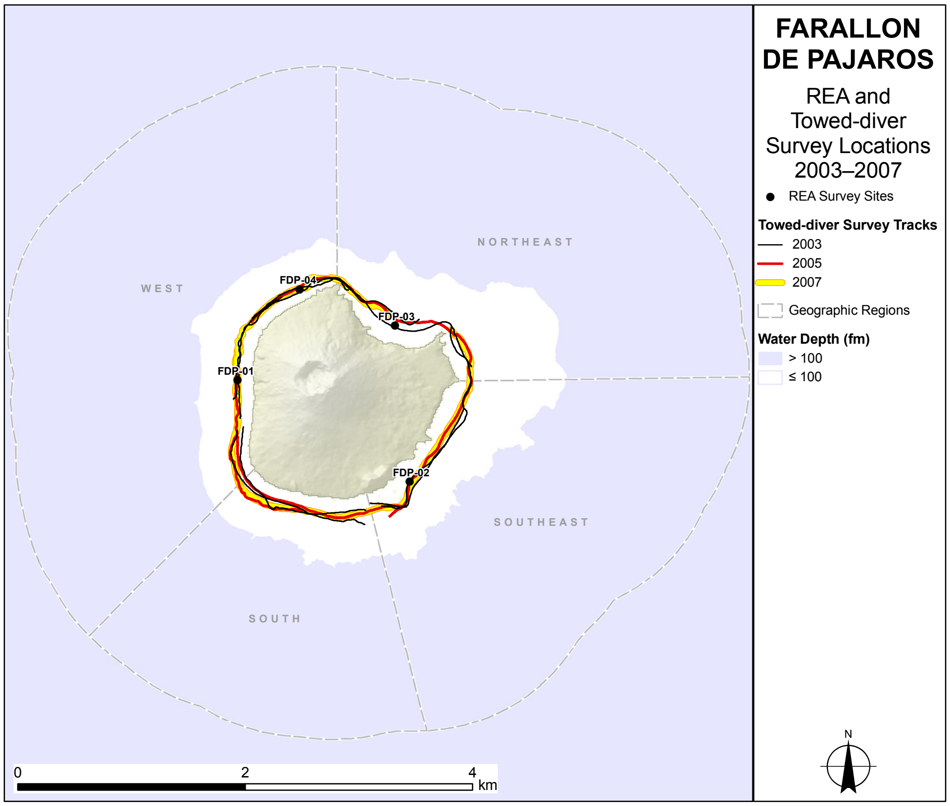


Figure 17.2a. Locations of REA and towed-diver benthic surveys conducted around Farallon De Pajaros during MARAMP 2003, 2005, and 2007. To aid discussion of spatial patterns, this map delineates 4 geographic regions: northeast, southeast, south and west.

Benthic habitat mapping data were collected around Farallon de Pajaros using a combination of acoustic and optical survey methods. MARAMP benthic habitat mapping surveys conducted around Farallon de Pajaros, Asuncion, Maug, and Supply Reef with multibeam sonar covered a total area of 3856 km^2 in 2007. Optical validation and habitat characterization were completed using towed-diver surveys that documented live-hard-coral cover, sand cover, and habitat complexity. The results of these efforts are discussed in Section 17.3: "Benthic Habitat Mapping and Characterization."

Information on the condition, abundance, diversity, and distribution of biological communities around Farallon de Pajaros was collected using REA and towed-diver surveys. The results of these surveys are reported in Sections 17.5–17.8: "Corals and Coral Disease," "Algae and Algal Disease," "Benthic Macroinvertebrates," and "Reef Fishes." The numbers of surveys conducted during MARAMP 2003, 2005, and 2007 are presented in Table 17.2a, along with their mean depths and total areas or length.

Spatial and temporal observations of key oceanographic and water-quality parameters influencing reef conditions around Farallon de Pajaros were collected using (1) subsurface temperature recorders (STRs) designed for long-term observations of high-frequency variability of temperature, (2) closely spaced conductivity, temperature, and depth (CTD) profiles of the vertical structure of water properties, and (3) discrete water samples for nutrient and chlorophyll-a analyses. CTD casts

Table 17.2a. Numbers, mean depths (m), and total areas (ha) of REA and towed-diver surveys conducted around Farallon de Pajaros during MARAMP 2003, 2005, and 2007. REA survey information is provided for both fish and benthic surveys, the latter of which includes surveys of corals, algae, and macroinvertebrates.

Survey Type	Survey Detail	Year		
REA		**2003**	**2005**	**2007**
Fish	Number of Surveys	4	3	3
	Mean Depth (m)	13.4 (SD 2.3)	14.5 (SD 0.5)	14.5 (SD 0.5)
Benthic	Number of Surveys	4	3	3
	Mean Depth (m)	13.4 (SD 2.3)	14.5 (SD 0.5)	14.5 (SD 0.5)
Towed Diver		**2003**	**2005**	**2007**
	Number of Surveys	8	4	4
	Total Survey Area (ha)	13.4	7.5	8.6
	Mean Depth (m)	13.7 (SD 1.6)	14.9 (SD 3.1)	15.2 (SD 1.7)

were performed during MARAMP 2003, 2005, and 2007, and water sampling was conducted during MARAMP 2005 and 2007 (see Chapter 2: "Methods and Operational Background," Section 2.3: "Oceanography and Water Quality"). A summary of deployed instruments and collection activities is provided in Table 17.2b. Results are discussed in Section: 17.4: "Oceanography and Water Quality."

Table 17.2b. Numbers of STRs deployed, shallow-water and deepwater CTD casts performed, and water samples collected around Farallon De Pajaros during MARAMP 2003, 2005, and 2007. Shallow-water CTD casts and water samples were conducted from the surface to a 30-m depth and deepwater casts were conducted to a 500-m depth. Deepwater CTD cast information is presented in Chapter 3: Archipelagic Comparisons.

Observation Type	Year						
Instruments	**2003**	**2005**		**2007**		**2009**	**Lost**
	Deployed	**Retrieved**	**Deployed**	**Retrieved**	**Deployed**	**Retrieved**	
STR	1	–	1	1	6	6	1
CTD Casts	**2003**	**2005**		**2007**			**Total**
Shallow-water Casts	8	12		7			27
Deepwater Casts	–	8		1			9
Water Samples		**2005**		**2007**			**Total**
		4		3			7

Towed-diver Surveys: Depths

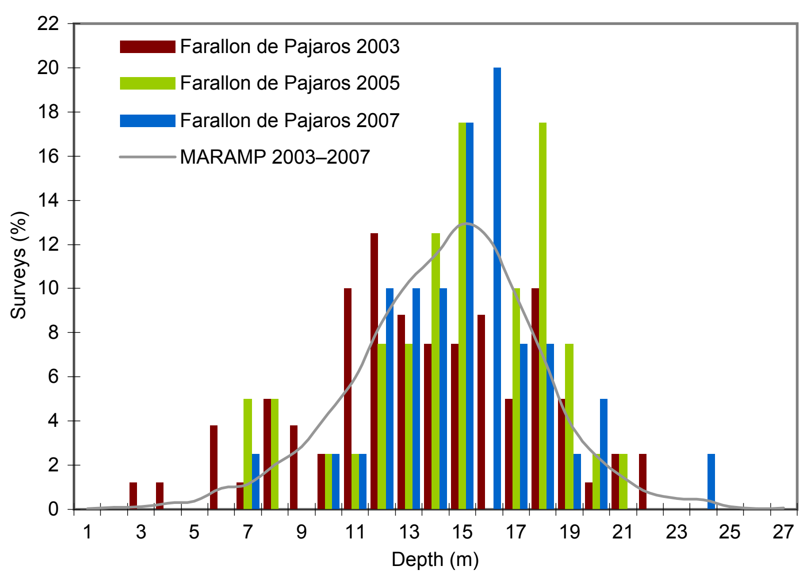


Figure 17.2b. Depth histogram plotted from mean depths of 5-min segments of towed-diver surveys conducted on forereef habitats around Farallon de Pajaros during MARAMP 2003, 2005, and 2007. Mean segment depths were derived from 5-s depth recordings. Segments for which no depth was recorded were excluded. The grey line represents average depth distribution for all towed-diver surveys conducted around the Mariana Archipelago during MARAMP 2003, 2005, and 2007.

Figures 17.2b and c illustrate the locations and depths of towed-diver-survey tracks around Farallon de Pajaros and should be referenced when further examining results of towed-diver surveys from MARAMP 2003, 2005, and 2007.

During MARAMP 2003, 8 towed-diver surveys were conducted along the forereef slopes around Farallon de Pajaros (Figs. 17.2b and 17.2c, top panel). The mean depth of all survey segments was 13.7 m (SD 1.6), and the mean depth of individual surveys ranged from 12.1 m (SD 6.4) to 16.3 m (SD 4.5).

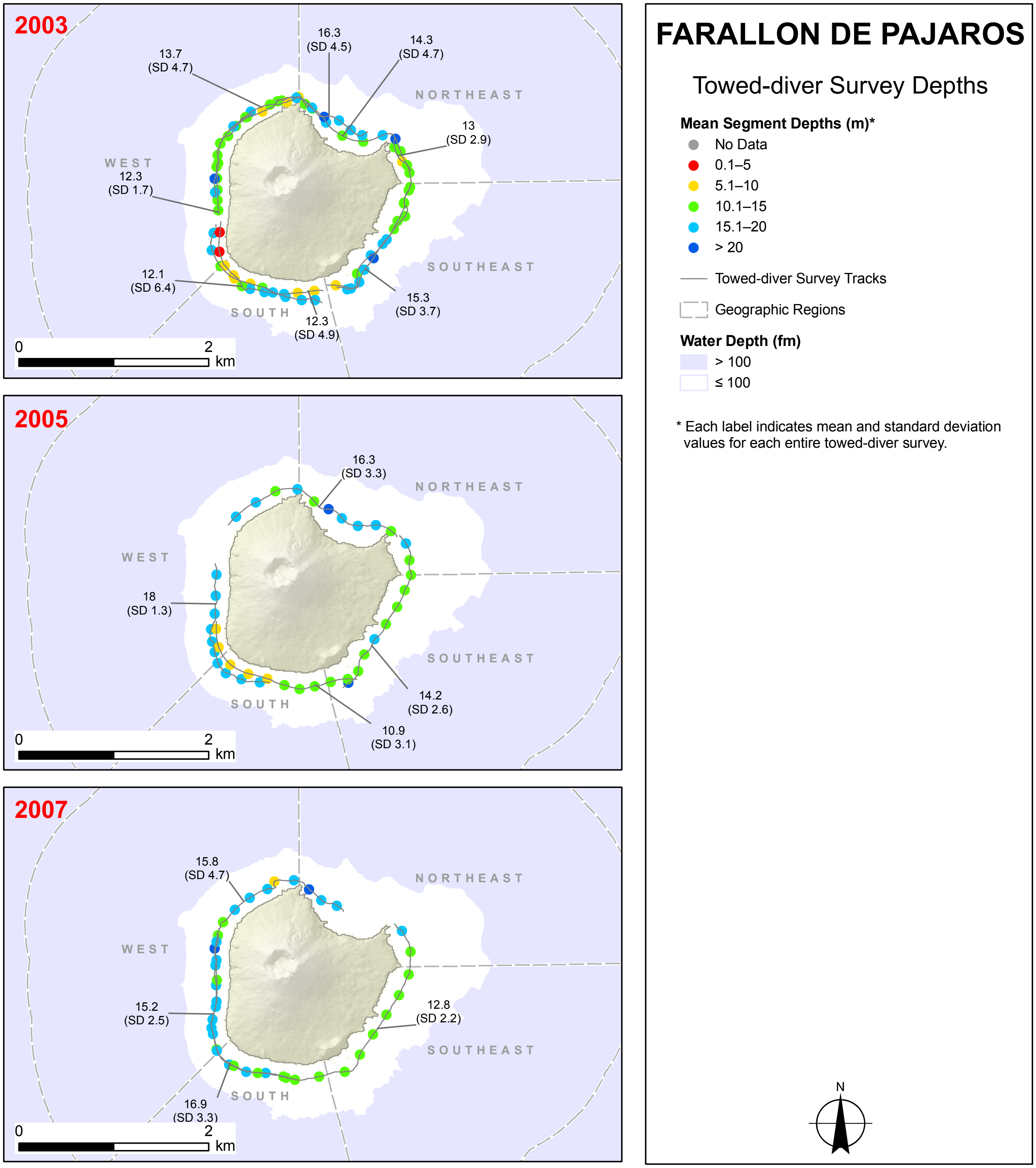


Figure 17.2c. Depths and tracks of towed-diver surveys conducted on forereef habitats around Farallon De Pajaros during MARAMP 2003, 2005, 2007. Towed-diver-survey tracks are color coded by mean depth for each 5-min segment. A black-text label shows the mean depth (and standard deviation) for each entire towed-diver survey. Each depth represents the depth of the benthic towboard during each survey; towboards are maintained nominally 1 m above the benthic substrate.

During MARAMP 2005, 4 towed-diver surveys were conducted along the forereef slopes around most of Farallon de Pajaros (Figs. 17.2b and 17.2c, middle panel). The mean depth of all survey segments was 14.9 m (SD 3.1), and the mean depth of individual surveys ranged from 10.9 m (SD 3.1) to 18 m (SD 1.3).

During MARAMP 2007, 4 towed-diver surveys were conducted along the forereef slopes around most of Farallon de Pajaros (Figs. 17.2b and 17.2c, bottom panel). The mean depth of all survey segments was 15.2 m (SD 1.7), and the mean depth of individual surveys ranged from 12.8 m (SD 2.2) to 16.9 m (SD 3.3).

17.3 Benthic Habitat Mapping and Characterization

Benthic habitat mapping and characterization surveys around the island of Farallon de Pajaros were conducted during MARAMP 2003, 2005, and 2007 using acoustic multibeam sonar, underwater video and still imagery, and towed-diver observations. Acoustic multibeam sonar mapping provided bathymetric and backscatter data products over the depth range of ~ 15–1500 m. Optical validation and benthic characterization were performed using towed-diver surveys conducted at depths < 5–26 m.

17.3.1 Acoustic Mapping

Multibeam acoustic bathymetry and backscatter imagery (Fig. 17.3.1a) collected by the Coral Reef Ecosystem Division (CRED) around Farallon de Pajaros, Asuncion, Maug, and Supply Reef in 2007 encompassed an area of 3856 km^2.

Low-resolution multibeam bathymetry acquired during MARAMP 2007 suggests uniformly steep slopes with ridges that radiate out perpendicularly from this active volcanic island.

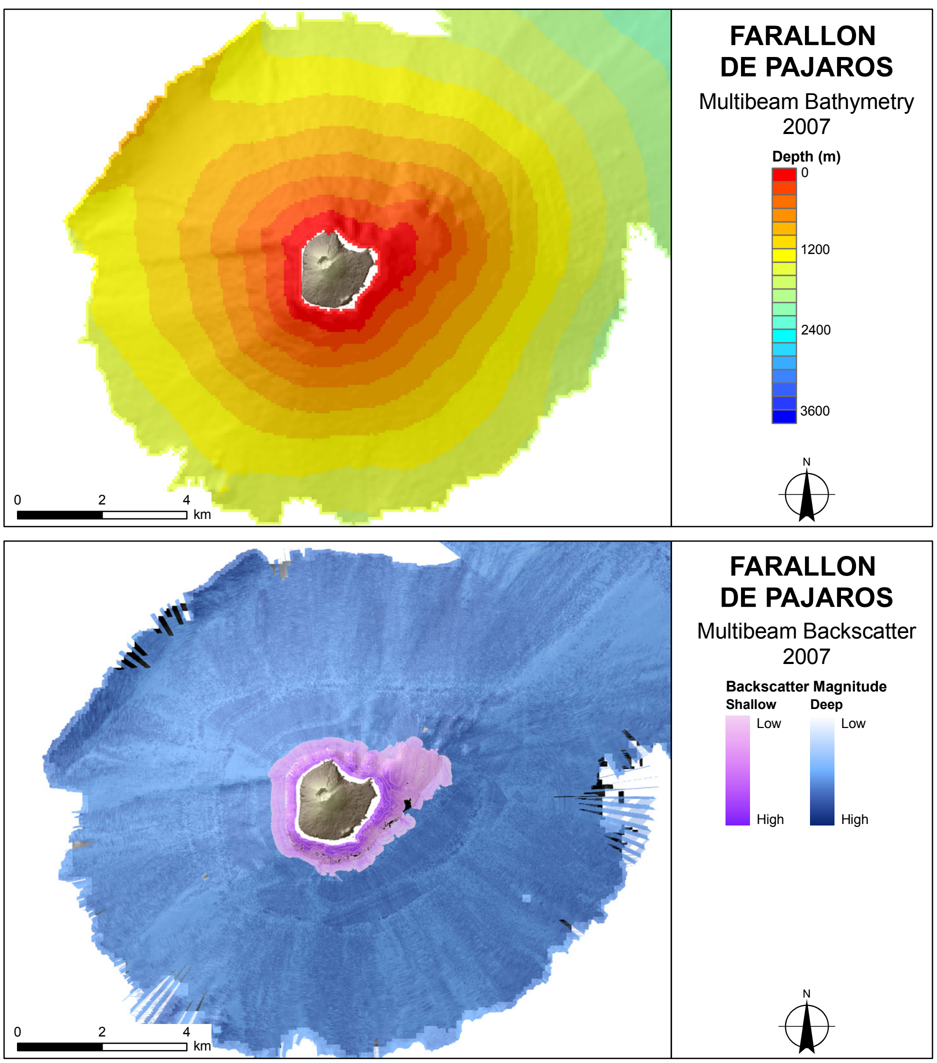


Figure 17.3.1a. Gridded (*top*) multibeam bathymetry (grid cell size: 60 m) and (*bottom*) backscatter (grid cell size: 5 m) collected around Farallon de Pajaros during MARAMP 2007 at depths of ~ 15–1500 m. Shallow-backscatter data (shown in purple) were collected using a 240 kHz Reson SeaBat 8101 ER sonar, and deep-backscatter data (shown in blue) were collected using a 30 kHz Kongsberg EM 300 sonar. Light shades represent low-intensity backscatter and may indicate acoustically absorbent substrates, such as unconsolidated sediment. Dark shades represent high-intensity backscatter and may indicate consolidated hard-bottom or coral substrates.

Low-resolution backscatter data acquired around Farallon de Pajaros show relatively uniform backscatter intensity, with some bands of lower intensity backscatter on the northwest and southwest flanks. Topographic features revealed by the high-resolution multibeam data and derivatives are described in more detail in the following section.

High-resolution Multibeam Bathymetry and Derivatives

High-resolution multibeam data collected in nearshore (depths of 0–800 m) waters around Farallon de Pajaros were combined into a grid at 10-m resolution to allow for the identification of fine-scaled features (Fig. 17.3.1b). These high-resolution data have also been used to derive maps showing slope (Fig. 17.3.1c), rugosity (Fig. 17.3.1d), and bathymetric position index (BPI) zones (Fig. 17.3.1e). Together, these maps provide layers of information to characterize the benthic habitats around Farallon de Pajaros.

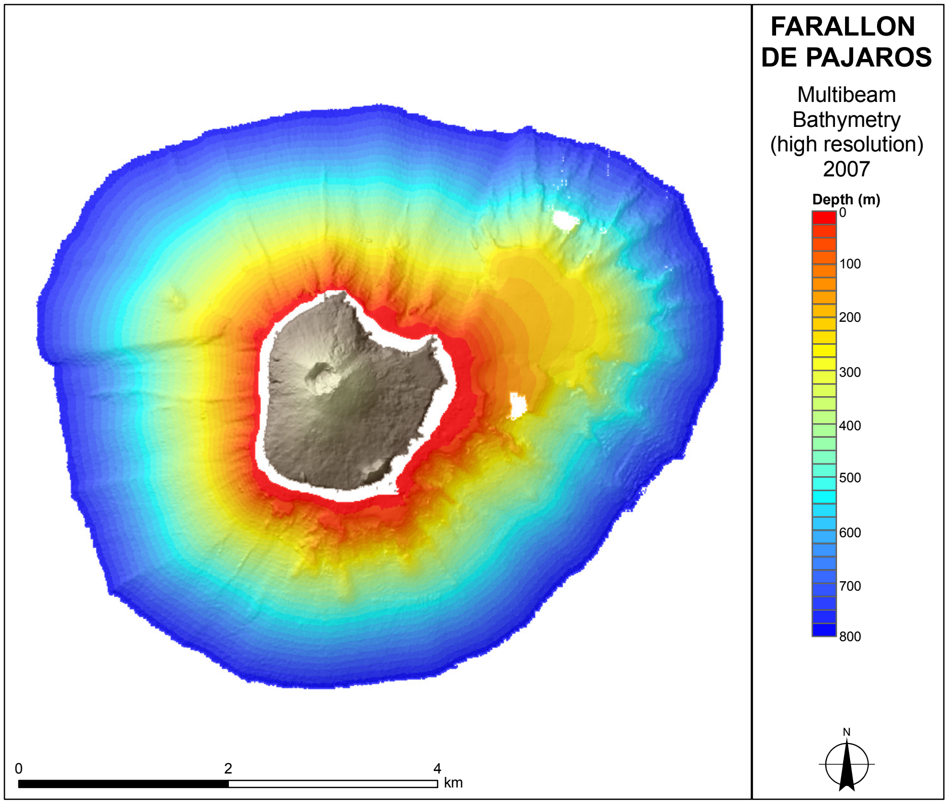


Figure 17.3.1b. High-resolution multibeam bathymetry collected around Farallon de Pajaros during MARAMP 2007. This 10-m bathymetry grid, clipped at 800 m, is used as the basis for slope, rugosity, and BPI derivatives.

Steeply sloping flanks characterize much of the seabed around Farallon de Pajaros with very few flat BPI zones identified (Figs. 17.3.1c and e). High-resolution multibeam bathymetry reveals ridges on the flanks that extend from depths < 30 m to depths of 400–600 m. The slope along the sides of these ridges is commonly 20°–30° although along some ridges very steep slopes > 50° occur (Figs. 17.3.1b and c).

South and east of Farallon de Pajaros, high-resolution multibeam bathymetry reveals a narrow shelf area at depths of 10–40 m and a second, larger shelf, which fans out from the northeastern point of Farallon de Pajaros and gently deepens from a depth of ~ 150 m to 250–300 m. The slope and rugosity analyses both suggest that the shelf, which may be related to an older portion of the volcano, has a smooth surface. Both shelves are surrounded by steep slopes and numerous small ridges and channels that descend from the shelf edges. Blocky material revealed on these and other flanks around Farallon de Pajaros suggests mass-wasting (movement of soil and surface materials by gravity).

West of Farallon de Pajaros, the seabed is characterized by uniformly steep slopes of 20°–50°, with the steepest slopes occurring at depths < 100 m (Fig. 17.3.1c).

In the shallowest waters surveyed, the BPI analysis identifies reef crests (Fig. 17.3.1e). However, this classification is likely an artifact of the methodology, since no data are available for immediately inshore areas and no comparison can be made to the innermost cells of the grid. Instead, these areas probably should be characterized as slopes

Figure 17.3.1c. Slope (°) of 10-m bathymetric grid around Farallon de Pajaros. Derived from data collected in 2007, this map reflects the maximum rate of change in elevation between neighboring cells with the steepest slopes shown in the darkest shades of blue and the flattest areas in yellow shades.

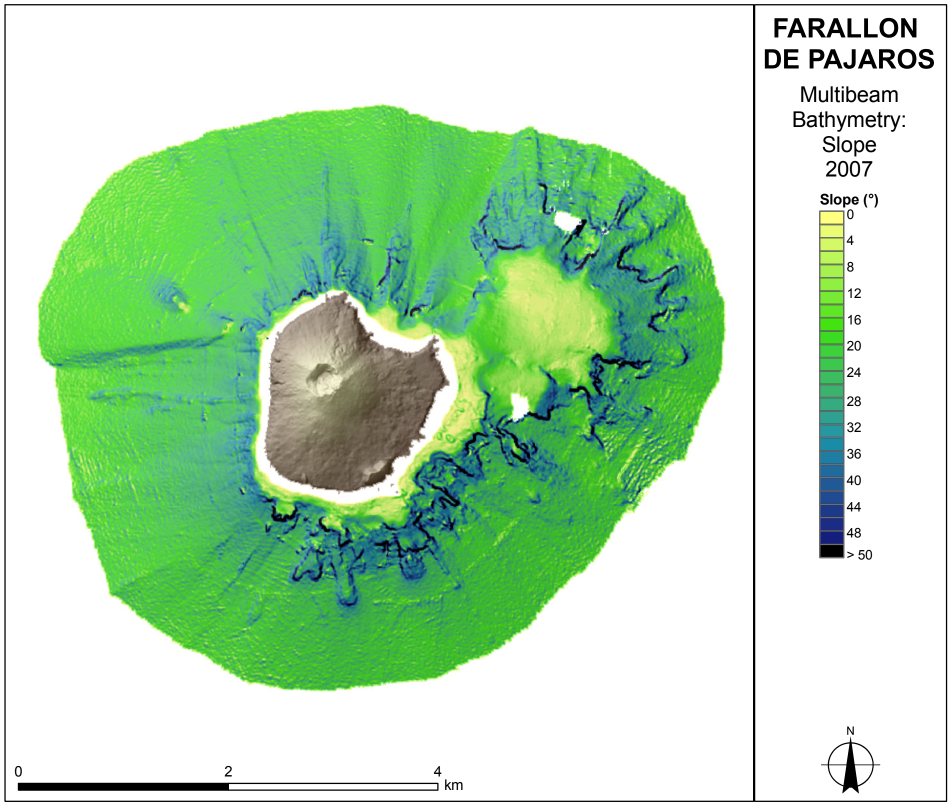
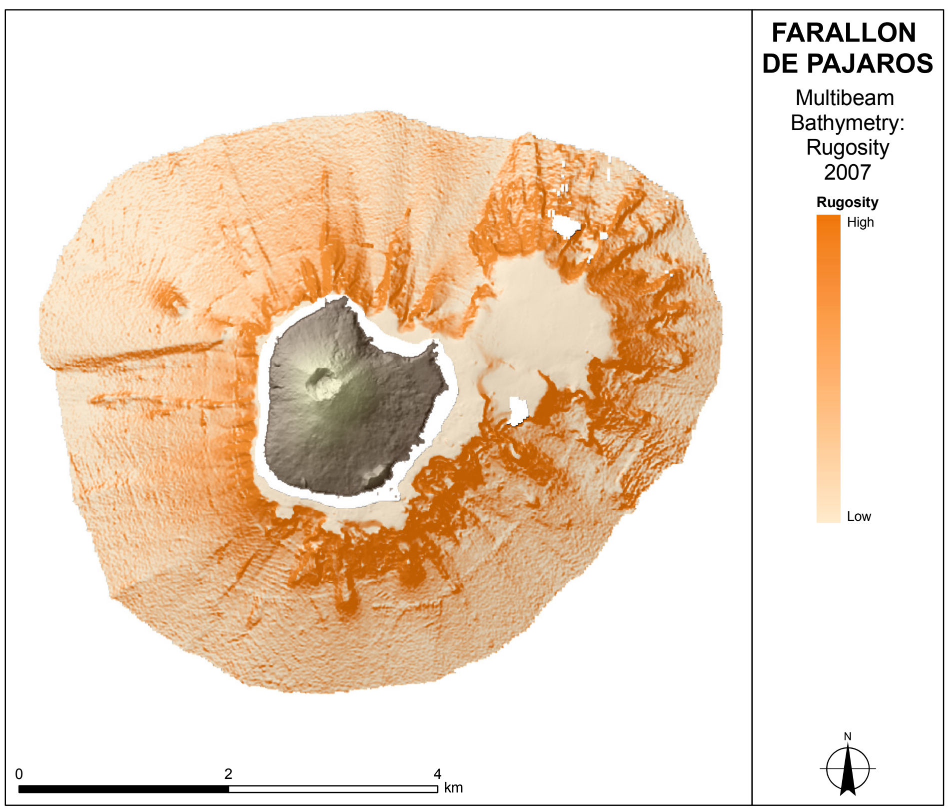


Figure 17.3.1d. Rugosity of 10-m bathymetric grid around Farallon de Pajaros. Derived from data collected in 2007, these rugosity values are a measure of the ratio of surface area to planimetric area within a given cell's neighborhood and indicate topographic roughness.



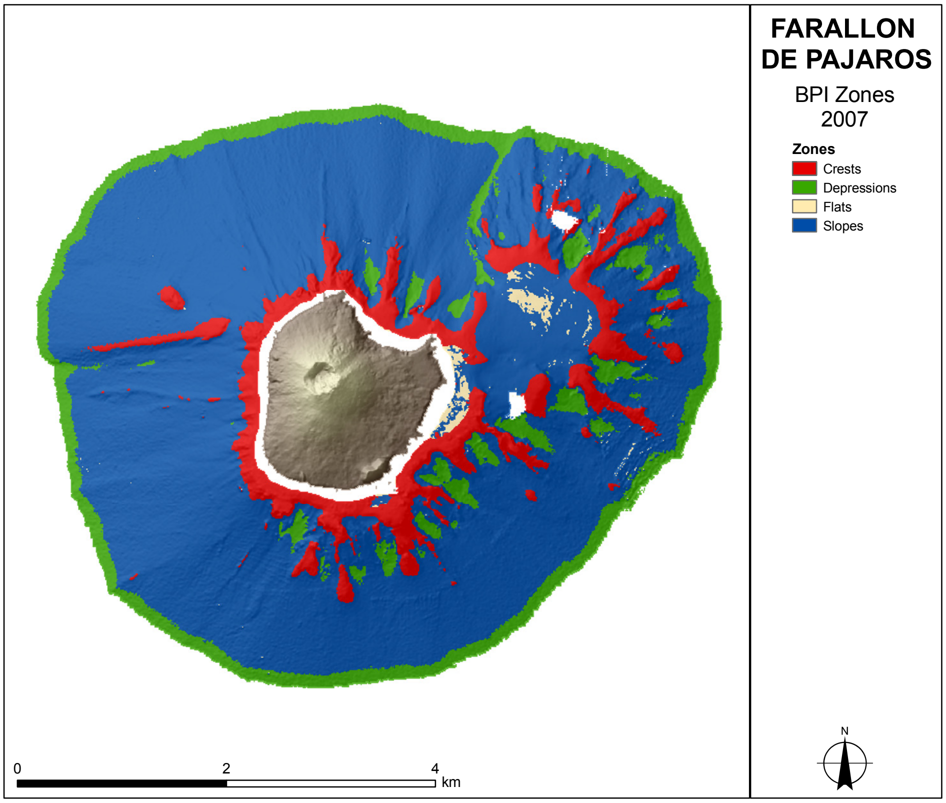


Figure 17.3.1e. BPI Zones of 10-m bathymetric grid around Farallon de Pajaros derived from data collected in 2007. BPI is a second-order derivative of bathymetry that evaluates elevation differences between a focal point and the mean elevation of the surrounding cells within a user-defined circle. Four BPI Zones—crests, depressions, flats, and slopes—were used in this analysis.

High-resolution Multibeam Backscatter and Derivatives

High-resolution backscatter data were acquired around Farallon de Pajaros using a 240-kHz Reson SeaBat 8101 ER multibeam echosounder and a 30-kHz Kongsberg EM 300 sonar. This data set had some noticeable artifacts that impaired data

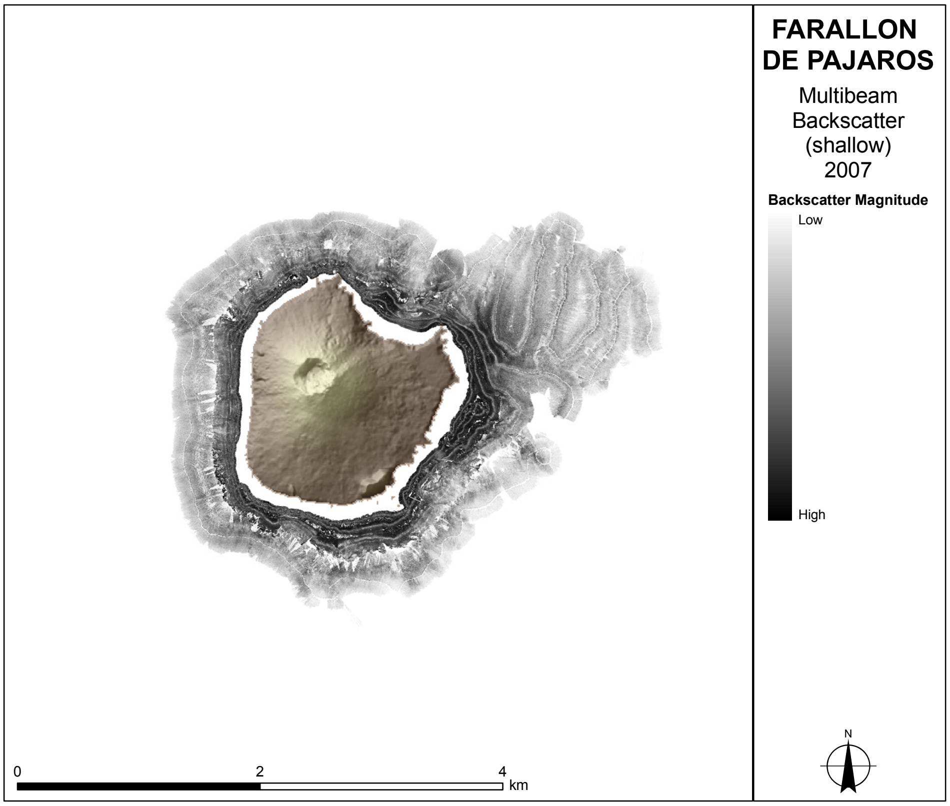


Figure 17.3.1f. Gridded, high-resolution, multibeam backscatter data (grid cell size: 1 m) collected around Farallon de Pajaros during MARAMP 2007. Light shades represent low-intensity backscatter and may indicate acoustically absorbent substrates. Dark shades represent high-intensity backscatter and may indicate consolidated hard-bottom and coral substrates.

quality, including a distinct difference in backscatter intensity between the shallow and deeper swaths around much of this island and large gaps in data between inner and outer swaths. Such artifacts may have resulted from any number of factors, such as the steep slopes occurring within the survey area, sea state, or changes in sonar settings during acquisition (discussed in more detail in Chapter 2: “Methods and Operational Background”, Section 2.2.2: “Acoustic Mapping”). Effects of artifacts were exacerbated in the hard–soft analysis, resulting in some substrate areas being falsely classified. Because of data quality issues, no hard–soft maps are presented for Farallon de Pajaros. However, some patterns in the backscatter intensity are discernable and probably reflect the nature of the seabed (Fig. 17.3.1f). High-intensity-backscatter values were observed on the shallow shelf areas east and south of this island. The steep flanks elsewhere were found in general to have low backscatter intensity. This observation suggests that substrates here may be predominantly soft, although, in these areas, the backscatter values may be strongly influenced by the steepness of the slopes in addition to the acoustic characteristics of the substrate.

High backscatter values were recorded on some of the ridges north and east of Farallon de Pajaros, suggesting that these may be characterized by hard substrate at or near the seabed surface. Between the ridges, low backscatter values were observed, which may be a result of soft sediments accumulating in the channels.

Low-intensity backscatter values were also recorded on the shelf northeast of Farallon de Pajaros. As slope would not be an influencing factor here, it is likely that these results suggest soft sediments on the shelf.

17.3.2 Optical Validation

Covering a distance of 29 km at depths of 4–24 m, 16 towed-diver optical-validation surveys of forereef habitats were conducted around Farallon de Pajaros during MARAMP 2003, 2005, and 2007 (for survey locations, see Figure 17.2a in Section 17.2: “Survey Effort”). At 5-min intervals within each survey, divers recorded percentages of sand cover and live-hard-coral cover and habitat complexity using a 6-level categorical scale from low to very high.

17.3.3 Habitat Characterization

Results from towed-diver optical-validation surveys, weighted by data from the shallow shelf areas unique to the east side of this island, suggest different seabed characteristics in the northeast and southeast regions in comparison to the south and west regions. The highest levels of sand cover were recorded on the shallow shelf extending from the large embayments in the northeast and southeast regions (Fig. 17.3.3a, top panel). This area also supported the lowest levels of habitat complexity around this island (Fig. 17.3.3a, middle panel). The main habitat type in this area was boulders on sand. In some locations, hard pavements were seen extending into sandy slopes.

In the west and south regions, low levels of sand cover were observed, generally ranging from 10% to 30% (Fig. 17.3.3a, top panel). The predominant habitat characterizing these regions was boulders on sand with some patches of rocky reef. Recorded levels of habitat complexity were higher in these regions than elsewhere around this island, falling mainly within the complexity category of medium to medium-high.

Observations from towed-diver surveys suggested very low levels of live coral cover, rarely exceeding 20%, in all of the areas surveyed (Fig. 17.3.2a, bottom panel). Live-coral cover was observed to be particularly uncommon (< 10%) in the northeast and south regions. The highest levels of live-coral cover were observed on the shallow shelf in the southeast region, where interpolated coral cover reached 30%. These low levels of coral cover may be a result of the recent volcanic activity, which may not have abated long enough for coral reef development; however, the steeply sloping boulder and sand habitats provide little substrate suitable for coral settlement.

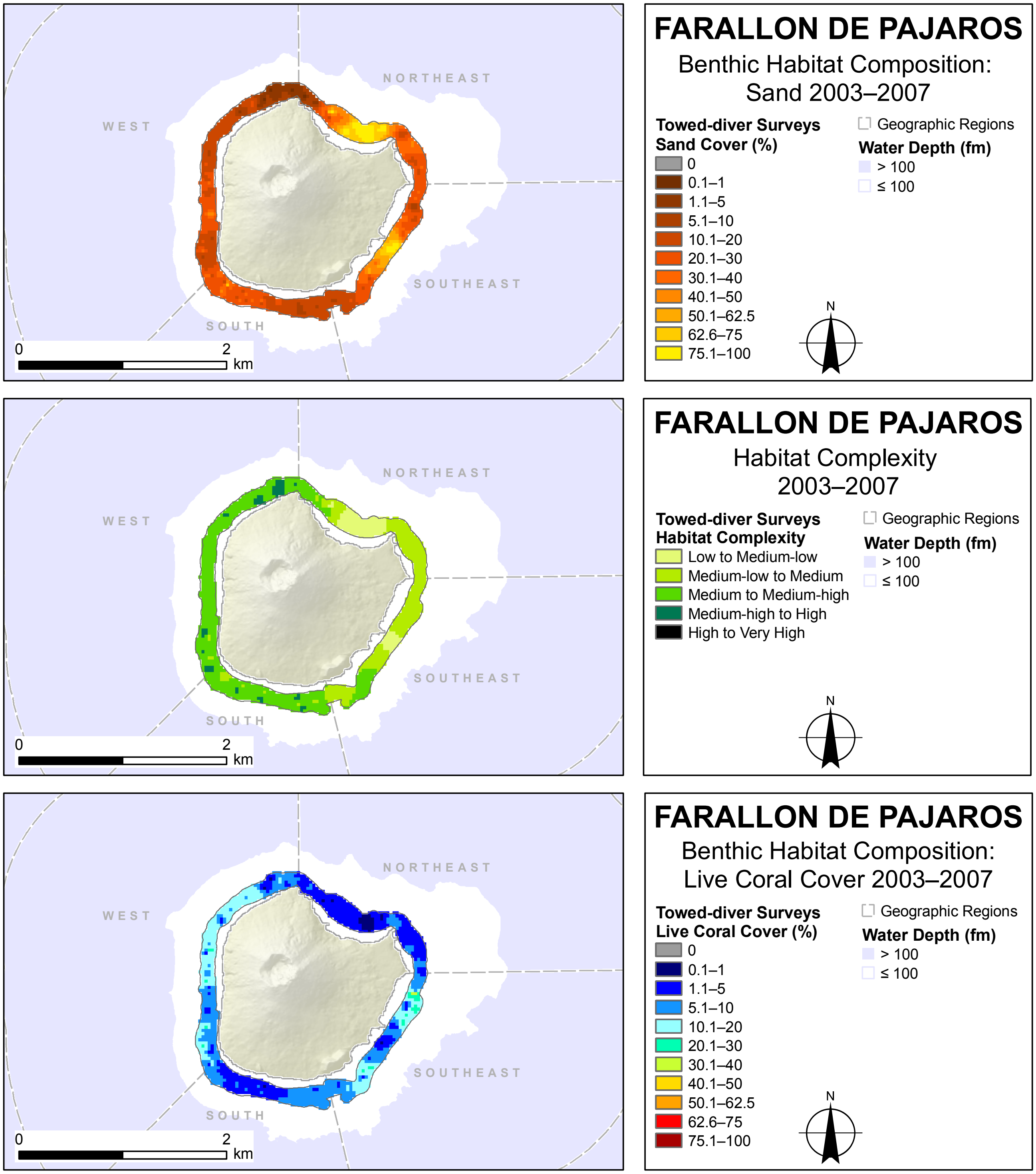


Figure 17.3.3a. Observations of (*top*) sand cover (%), (*middle*) benthic habitat complexity, and (*bottom*) cover (%) of live hard-corals from towed-diver surveys of forereef habitats conducted around Farallon de Pajaros during MARAMP 2003, 2005, and 2007.

17.4 Oceanography and Water Quality

17.4.1 Hydrographic Data

2003 Spatial Surveys

During MARAMP 2003, 8 shallow-water conductivity, temperature, and depth (CTD) casts were conducted in nearshore waters around the island of Farallon de Pajaros on August 30. Spatial comparisons of water properties at a depth of 10 m suggest small differences in temperature (0.26°C), salinity (0.03 psu), density (0.1 kg m^{-3}), and beam transmission (< 0.75%) values (Fig. 17.4.1a). Vertical comparisons of CTD profiles reveal differences in stratification around Farallon de Pajaros: well-mixed waters were recorded in the west and northeast regions (casts 1–4), and highly stratified waters were recorded in the south and southeast regions and part of the northeast region (casts 5–8), where the moderate differences in temperature (0.49°C), density (0.4 kg m^{-3}), and beam transmission (1.53%) values and small difference in salinity (0.08 psu) values were greater than the differences found in the well-mixed area (Fig. 17.4.1b). These observed differences in stratification around this island are likely a result of enhanced mixing on the wind-exposed east side and surface heating of the upper water column on the leeward side.

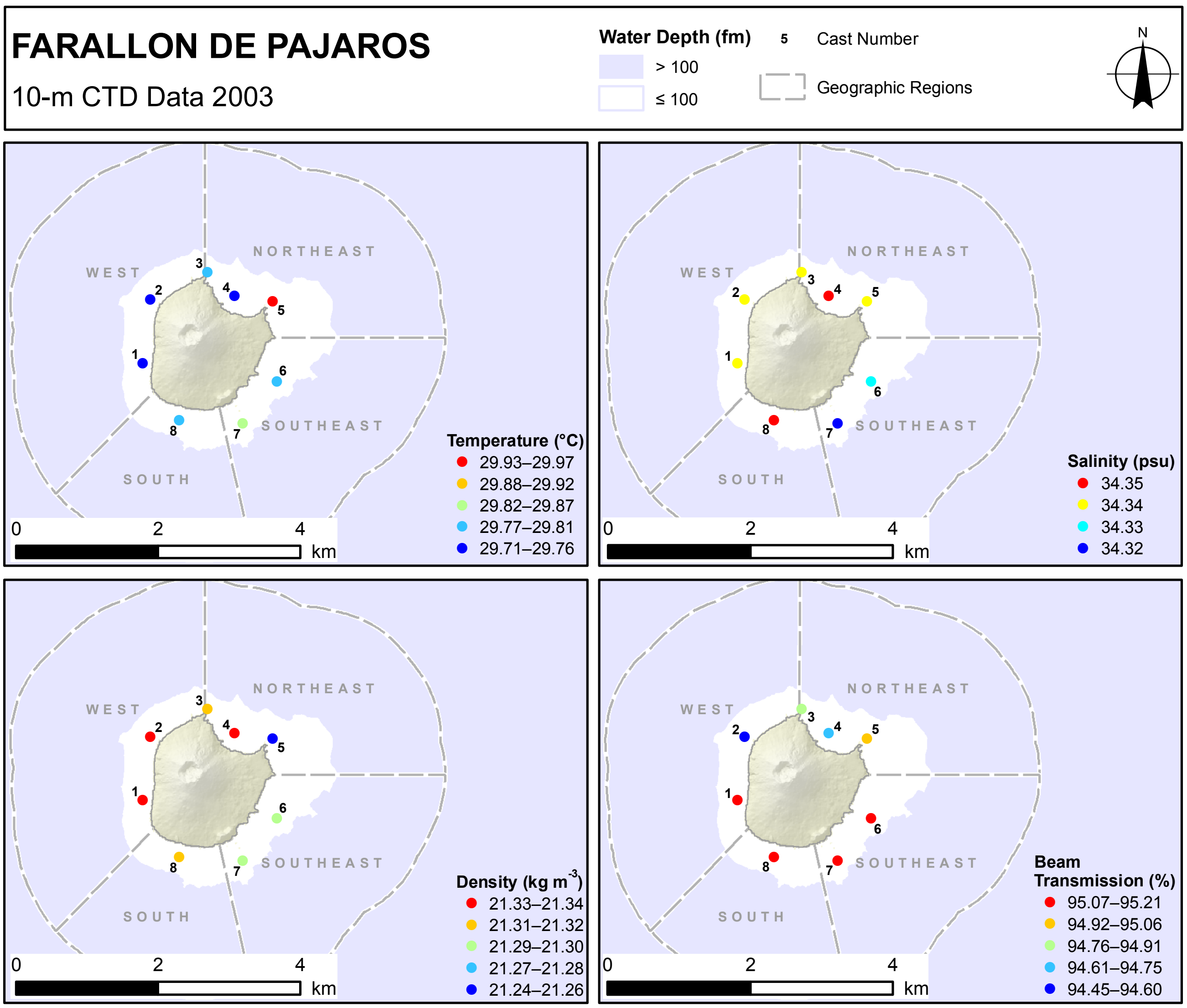


Figure 17.4.1a. Values of (*top left*) water temperature, (*top right*) salinity, (*bottom left*) density, and (*bottom right*) beam transmission at a 10-m depth from shallow-water CTD casts around Farallon de Pajaros on August 30 during MARAMP 2003.

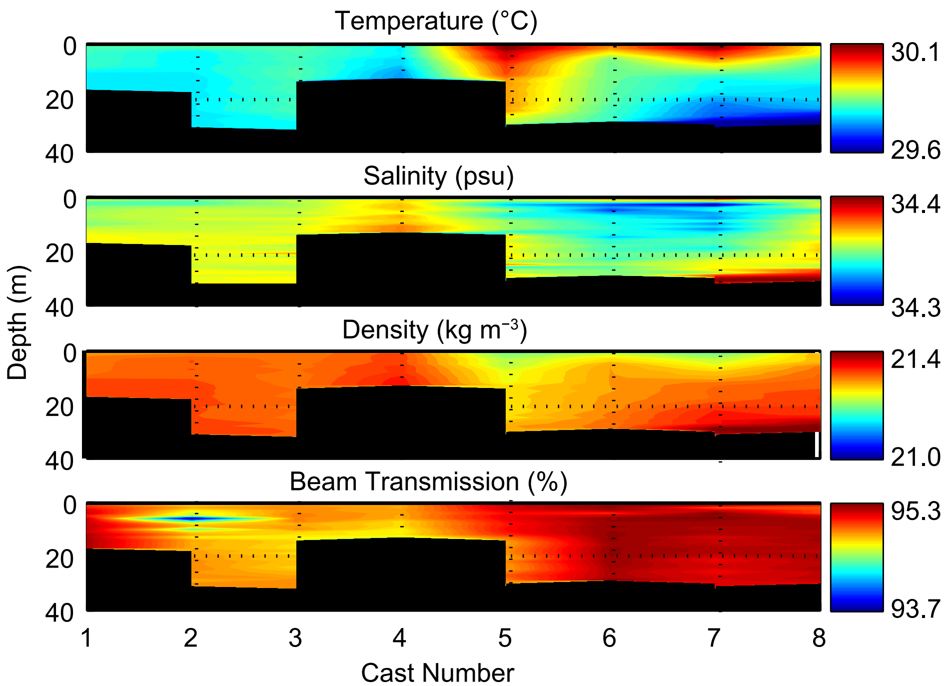


Figure 17.4.1b. Shallow-water CTD cast profiles to a 30-m depth around Farallon de Pajaros on August 30 during MARAMP 2003, including temperature (°C), salinity (psu), density (kg m^{-3}), and beam transmission (%). Profiles, shown sequentially in a left-to-right direction in this graph, correspond to cast locations that are numbered sequentially 1–8 in a clockwise direction around Farallon de Pajaros. For cast locations and numbers around this island in 2003, see Figure 17.4.1a.

2005 Spatial Surveys

During MARAMP 2005, 12 shallow-water CTD casts were conducted in nearshore waters around Farallon de Pajaros on September 10. Spatial comparisons of water properties at a depth of 10 m suggest small ranges in temperature (0.12°C), salinity (0.04 psu), density (0.03 kg m^{-3}), and beam transmission (< 0.31%) values (Fig. 17.4.1c). Vertical comparisons of CTD profiles reveal a generally well-mixed water column with small differences in temperature (0.22°C), salinity (0.06 psu), density (0.09 kg m^{-3}), and beam transmission (1.48%) values (Fig. 17.4.1d).

Water samples were collected in concert with shallow-water CTD casts at 4 select locations around Farallon de Pajaros in 2005 to assess water-quality conditions. The following ranges of measured parameters were recorded: chlorophyll-*a* (Chl-*a*), 0.29–1.15 µg L^{-1}; total nitrogen (TN), 0.039–0.44 µM; nitrate (NO_3^-), 0.017–0.022 µM; nitrite (NO_2^-), 0.021–0.023 µM; phosphate (PO_4^{3-}), 0.004–0.008 µM; and silicate [$Si(OH)_4$], 0.65–1.41 µM. Chl-*a* values were highest in the south and southeast regions; total nitrogen, nitrate, nitrite, and phosphate values were similar in all regions; and silicate values were higher in the west and northeast regions than in the south and southeast regions (Fig. 17.4.1e).

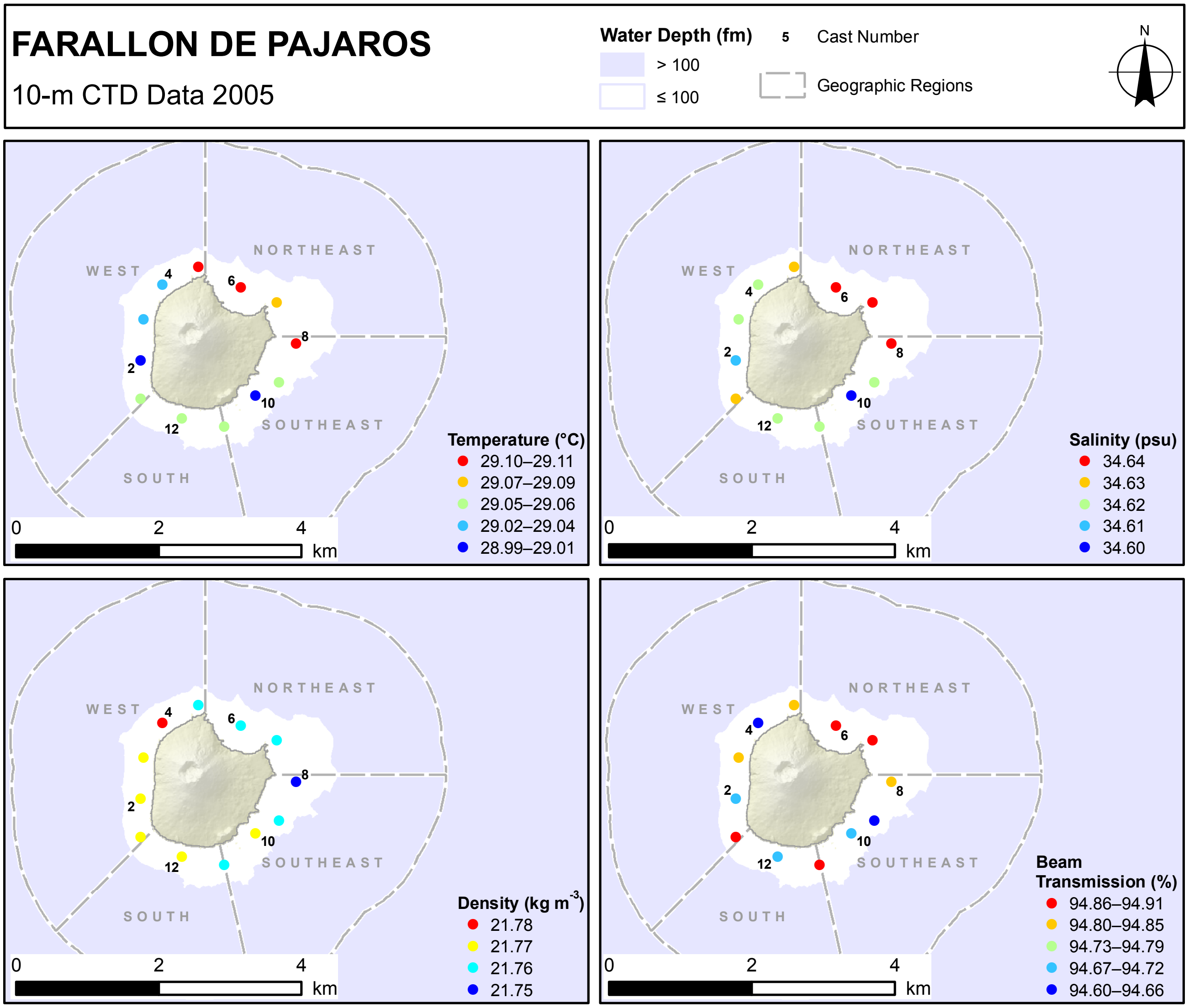
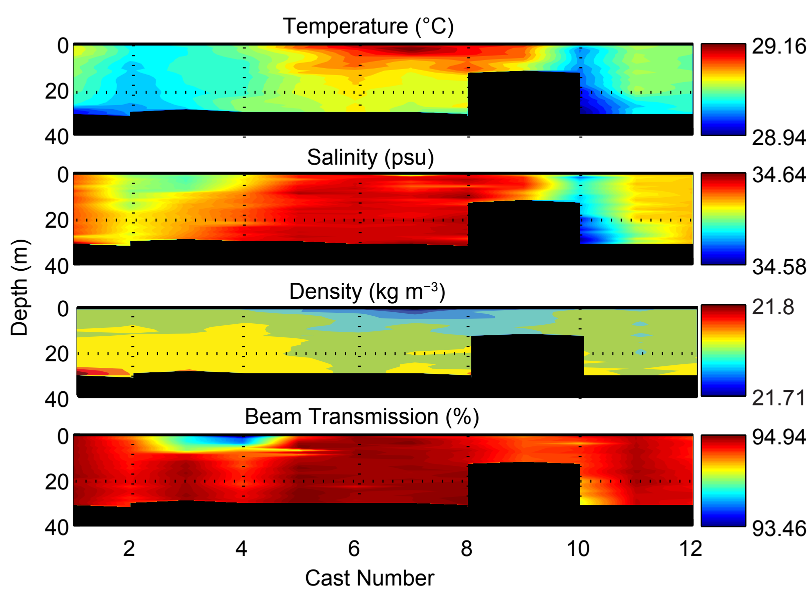


Figure 17.4.1c. Values of (*top left*) water temperature, (*top right*) salinity, (*bottom right*) density, and (*bottom left*) beam transmission at a 10-m depth from shallow-water CTD casts around Farallon de Pajaros on September 10 during MARAMP 2005.

Figure 17.4.1d. Shallow-water CTD cast profiles to a 30-m depth around Farallon de Pajaros on September 10 during MARAMP 2005, including temperature (°C), salinity (psu), density (kg m^{-3}), and beam transmission (%). Profiles, shown sequentially in a left-to-right direction in this graph, correspond to cast locations that are numbered sequentially 1–12 in a clockwise direction around Farallon de Pajaros. For cast locations and numbers around this island in 2005, see Figure 17.4.1c.



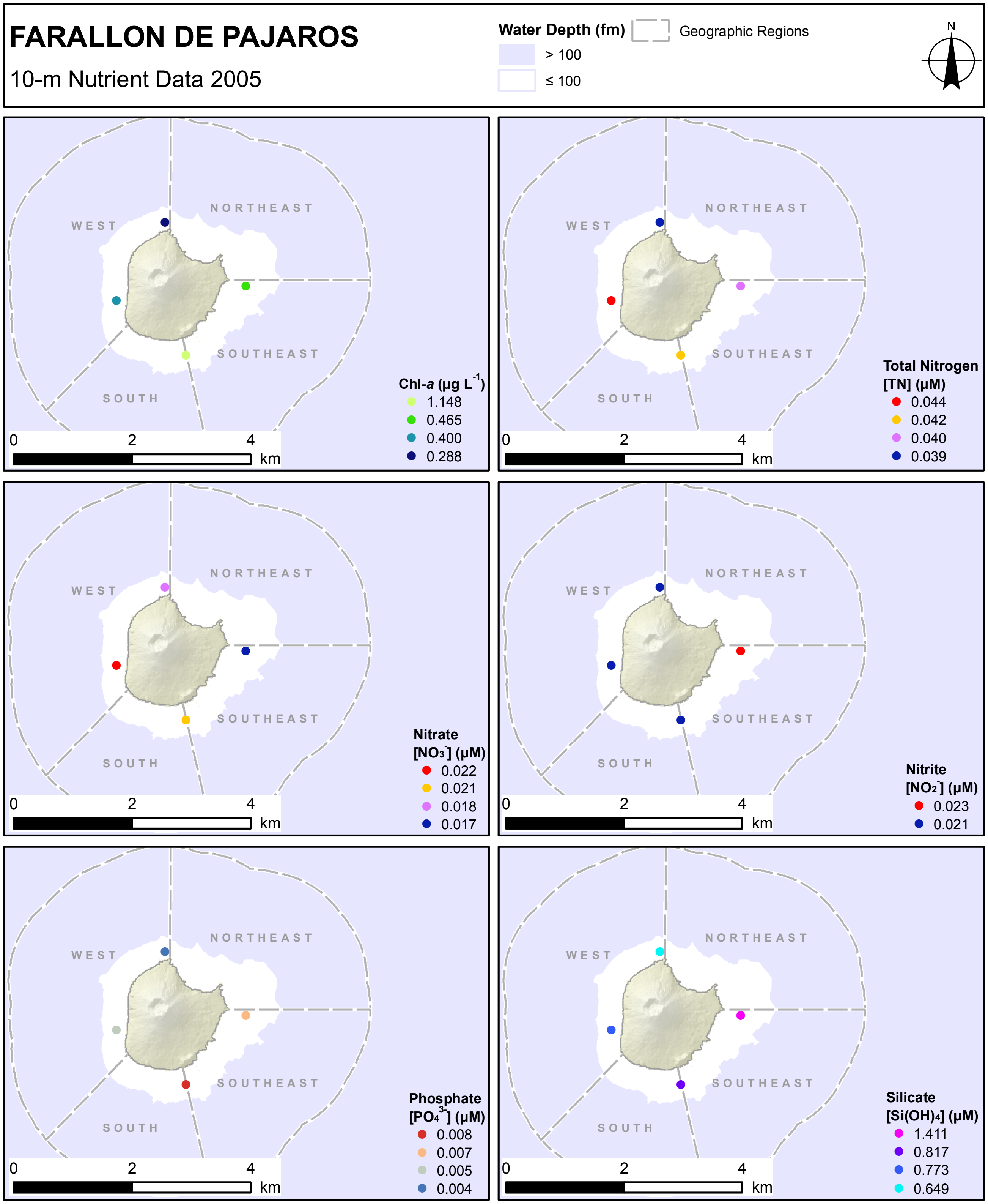


Figure 17.4.1e. Concentrations of (*top left*) Chl-*a*, (*top right*) total nitrogen, (*middle left*) nitrate, (*middle right*) nitrite, (*bottom left*) phosphate, and (*bottom right*) silicate at a 10-m depth, from water samples collected at Farallon de Pajaros on September 10 during MARAMP 2005.

2007 Spatial Surveys

During MARAMP 2007, 7 shallow-water CTD casts were conducted in nearshore waters around Farallon de Pajaros on June 3. Spatial comparisons of water properties at a depth of 10 m suggest generally moderate differences around this island with a large range in temperature measured up to 0.98°C (Fig. 17.4.1f). Vertical comparisons of CTD profiles reveal considerable temperature (3.44°C) and density (1.99 kg m^{-3}) stratification, a moderate difference in salinity (0.34 psu) levels, and a small difference in beam transmission (0.43%) values (Fig. 17.4.1g). The large variation in temperatures could have been a result of localized upwelling of subsurface waters. The definitive mechanism driving this process is unclear; however, subsurface temperature data obtained from Farallon de Pajaros, and presented later in this section (see Section 17.4.2: "Time-series Observations"), exhibit high-frequency fluctuations that are often associated with internal tide activity.

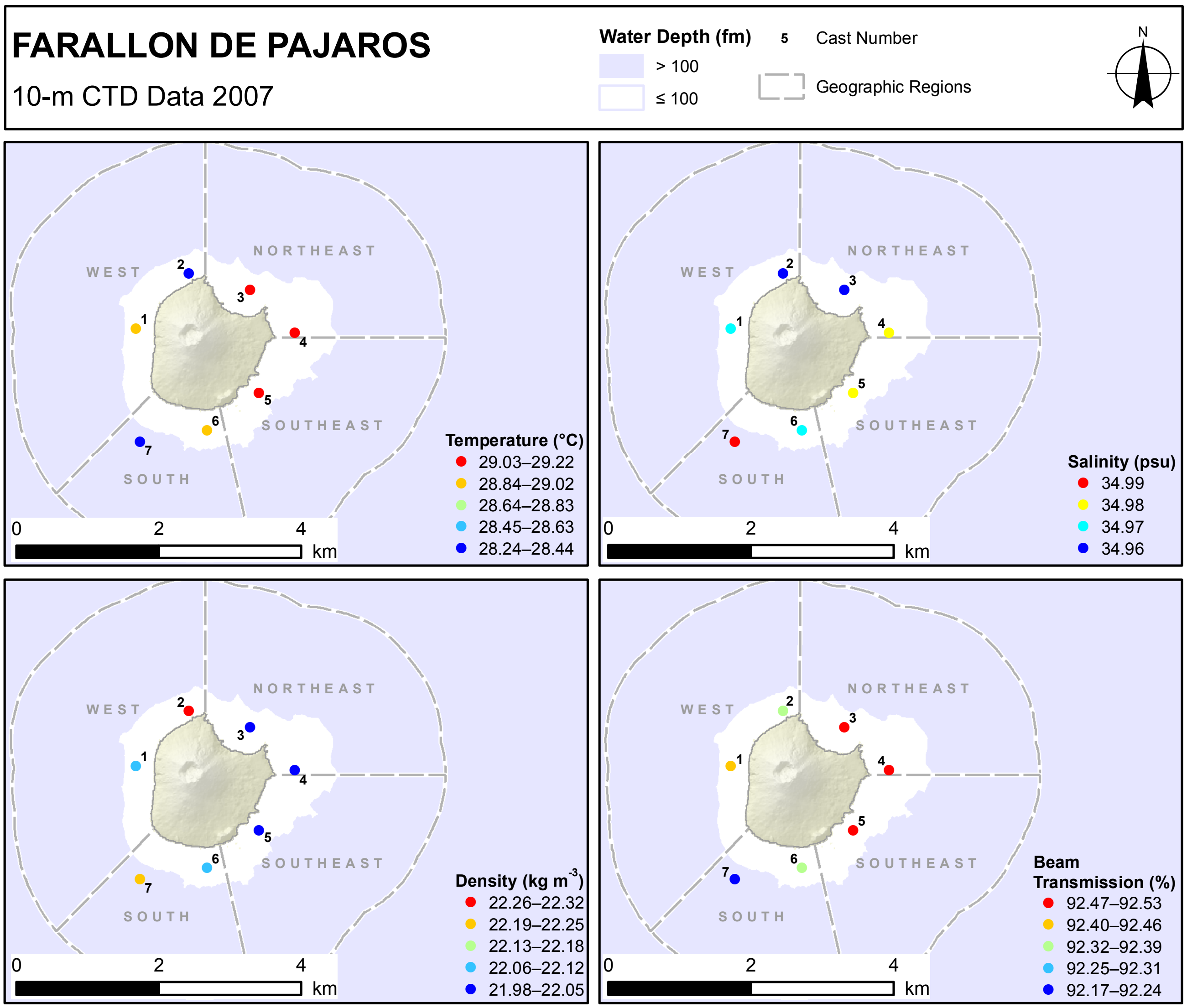


Figure 17.4.1f. Values of (top left) water temperature, (top right) salinity, (bottom left) density, and (bottom right) beam transmission at a 10-m depth from shallow-water CTD casts around Farallon de Pajaros on June 3 during MARAMP 2007.

Water samples were collected in concert with shallow-water CTD casts at 3 select locations around Farallon de Pajaros in 2007 to assess water-quality conditions. The following ranges of measured parameters were recorded: Chl-*a*, 0.01–0.07 µg L^{-1}; total nitrogen (TN), 0.014–0.024 µM; nitrate (NO_3^-), 0.006–0.013 µM; nitrite (NO_2^-), 0.008–0.011 µM; phosphate (PO_4^{3-}), 0.002–0.003 µM; and silicate [Si(OH)4], 1.27–1.77 µM. Water-quality parameters were generally observed at the relatively low levels typical of the Western Pacific Warm Pool's oligotrophic, oceanic surface layers. The lowest Chl-*a* value corresponded with the highest total nitrogen value in the west region (Fig. 17.4.1h). The lowest concentration of total nitrogen was found in the northeast region. Values for nitrate, nitrite, and phosphate were similar around this island. Silicate concentrations were highest in the south and lowest in the northeast region.

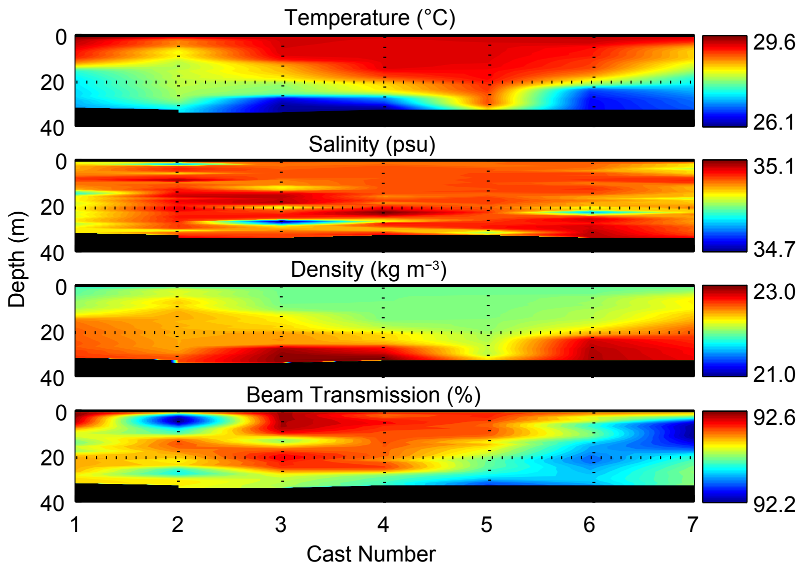


Figure 17.4.1g. Shallow-water CTD cast profiles to a 30-m depth around Farallon de Pajaros on June 3 during MARAMP 2007, including temperature (°C), salinity (psu), density (kg m^{-3}), and beam transmission (%).Profiles, shown sequentially in a left-to-right direction in this graph, correspond to cast locations that are numbered sequentially 1–7 in a clockwise direction around Farallon de Pajaros. For cast locations and numbers around this island in 2007, see Figure 17.4.1f.

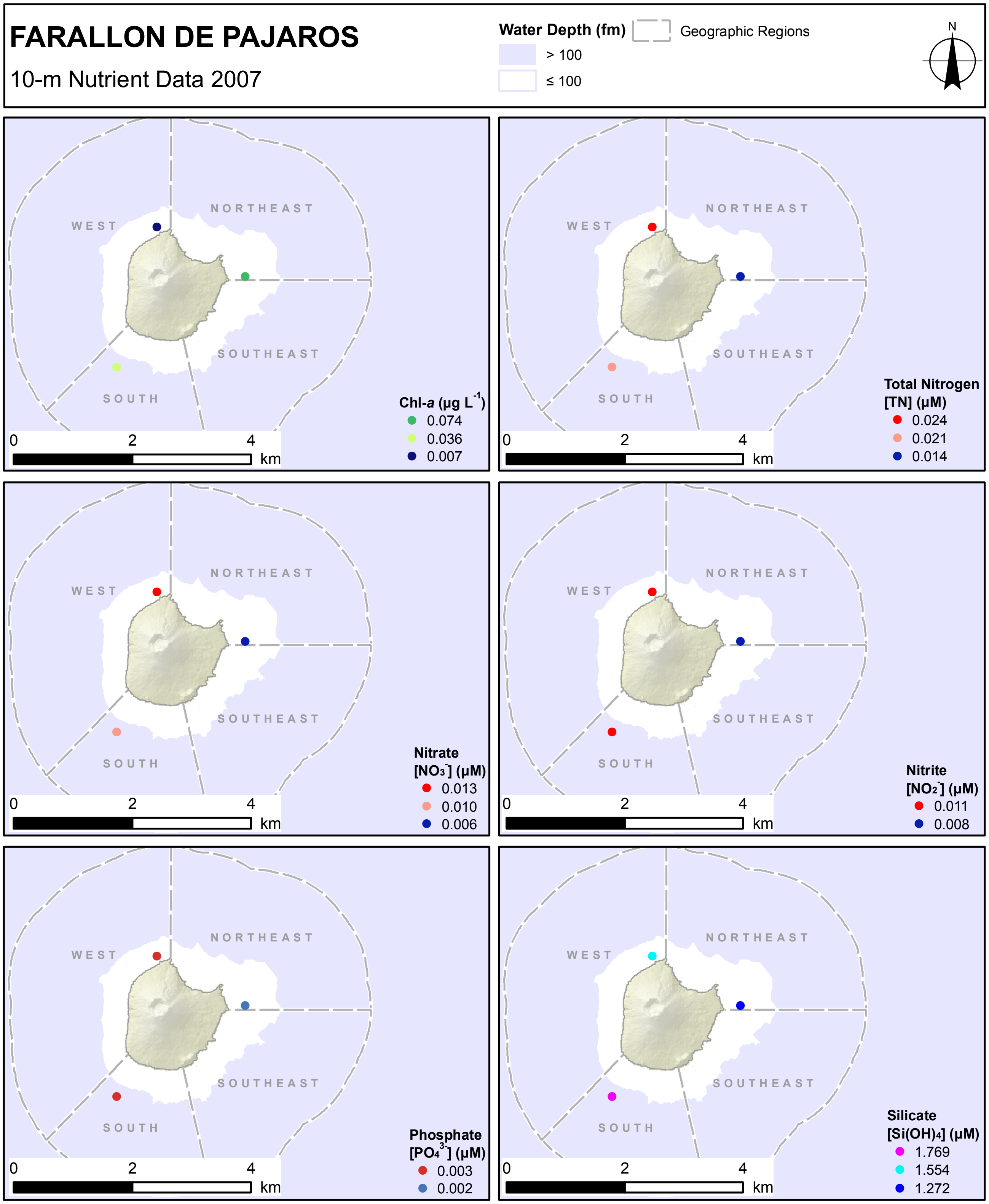


Figure 17.4.1h. Concentrations of (*top left*) Chl-*a*, (*top right*) total nitrogen, (*middle left*) nitrate, (*middle right*) nitrite, (*bottom left*) phosphate, and (*bottom right*) silicate at a 10-m depth, from water samples collected at Farallon de Pajaros on June 3 during MARAMP 2007.

Temporal Comparison

Comparisons of shallow-water CTD data between MARAMP surveys in 2003, 2005, and 2007 suggest a dynamic physical oceanographic environment around Farallon de Pajaros. Data from MARAMP 2003 and 2005 exhibit low spatial variability and moderate vertical variability, while the data from MARAMP 2007 exhibit substantial spatial variability in water properties. Cold-water intrusions (26.1°C, or 3.5°C colder than surface waters) originating from below a depth of 30 m were prominent in 2007, likely a result of upwelling or internal tide activity. Data were not collected with respect to a specific tidal cycle, which could be a source of oceanographic variability. Likewise, hydrographic variation between MARAMP survey years is likely a result of differences in season. MARAMP 2007 occurred in June, and MARAMP 2003 and 2005 occurred in August and September. This change was made to avoid the typhoon season and reduce the probability of weather disruptions.

Water-quality data obtained during MARAMP 2005 and 2007 suggest that nutrient concentrations are highly variable spatially and temporally and patterns within years are generally incongruous with one another. All of the parameters measured were lower in 2007 than in 2005, except for silicate. Chl-*a* concentrations were notably lower in 2007 than 2005. Differences between these survey years are likely a result of seasonal effects. Precipitation data show that MARAMP 2005 occurred during a period of seasonally high precipitation, while MARAMP 2007 occurred during a period of seasonally low precipitation (For precipitation information, see Chapter 3: "Archipelagic Comparisons," Section 3.1: "Oceanography and Water Quality: Seasonal Climatologies").

17.4.2 Time-series Observations

Between 2003 and 2007, subsurface temperature recorders (STRs) were deployed along 2 vertical transects at Farallon de Pajaros to collect time-series observations of a key oceanographic parameter. These data were collected in part to investigate the temperature and depth ranges of the possible internal tidal signal mentioned previously in the "2007 Spatial Surveys" part of this section. The locations, depths, time frames, and other details about these deployments are provided in Figures 17.4.2a and b.

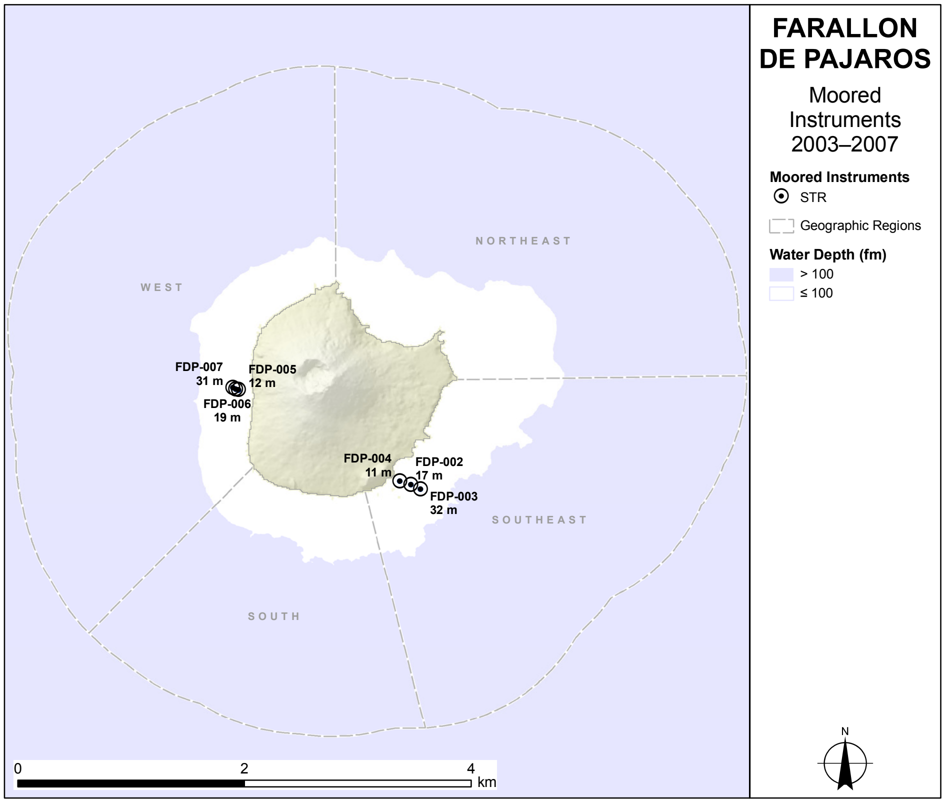
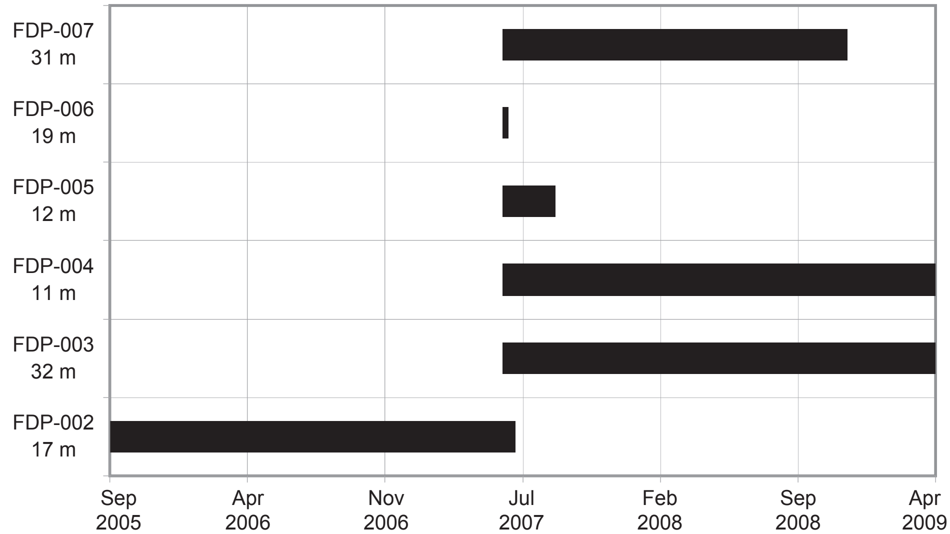


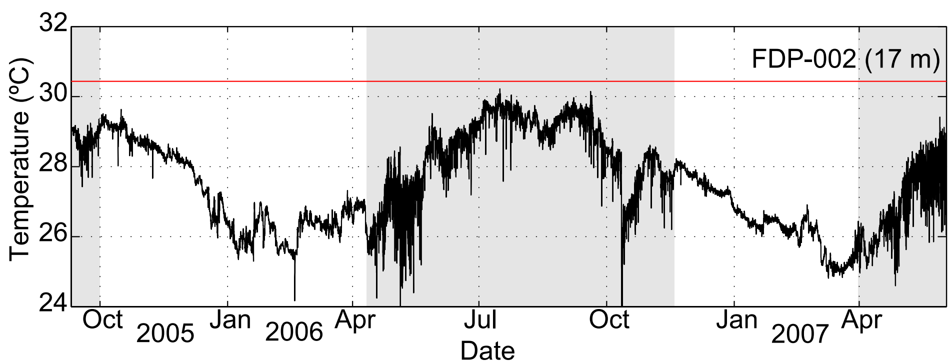
Figure 17.4.2a. Locations and depths of the STRs deployed at Farallon de Pajaros during MARAMP 2003, 2005, and 2007.

Figure 17.4.2b. Deployment timelines and depths of the STRs installed at Farallon de Pajaros during the period from September 2005 to April 2009. A solid bar indicates the period for which temperature data were collected by a single or a series of STRs deployed and retrieved at a mooring site. For more information about deployments and retrievals, see Table 17.2b in Section 17.2: "Survey Effort."



Temperature data from 1 STR located at a depth of 17 m in the southeast region of Farallon de Pajaros show typical seasonal temperature variability of ~ 5°C (Fig. 17.4.2c). Water temperatures reached ~ 29.5°C during the months of July–October and fell to a low of ~ 25°C during the months of January–May. Rapid (~ 12-h return periods) temperature fluctuations of 1°C–3°C were recorded in the springs of 2006 and 2007. Internal tides are generated when tidal currents interact with steep subsurface topography, resulting in high-frequency variability in temperature, salinity, dissolved nutrients, and suspended particle concentrations that differ significantly from shallow reefs to deep slopes. Although more research and additional data are needed to properly ascertain the nature of these signals, these high-frequency temperature plunges likely were the result of internal tides carrying colder, more nutrient-rich water from greater depths into the shallow-water coral reefs.

Figure 17.4.2c. Time-series observations of temperature from September 2005 to July 2007 collected from 1 STR mooring site at a depth of 17 m at Farallon de Pajaros (see Figure 17.4.2a for the location). A grey background indicates a period of high-frequency variability that likely resulted from internal tide activity. The red line shows the satellite-derived coral bleaching threshold.



17.4.3 Wave Watch III Climatology

Seasonal wave climatology for Farallon de Pajaros was derived using the NOAA Wave Watch III model for the period of January 1997–May 2008 (Fig. 17.4.3a), and seasons were selected to elucidate waves generated by typhoons, which most frequently occur during the period of August–December (for information about the Wave Watch III model, see Chapter 2: "Methods and Operational Background," Section 2.3.7: "Satellite Remote Sensing and Ocean Modeling"). In terms of consistency, the wave regime during this period was dominated by trade wind swells characterized by frequent (> 30 d per season), short-period (8–10 s), relatively small (2–3 m) wave events originating almost exclusively from the east (90°). Superimposed with these short-period trade wind swells were large (> 4 m), long-period (12–16 s) wave events principally from the south (180°), although they could originate from a broad directional source (120°–200°). These large, episodic waves primarily were generated by typhoons and occurred on annual to interannual time scales. Infrequent (~ 5 d per season), long-period (12–14 s) swells with moderate wave heights (2.5–3.5 m) occurred from the southwest (210°–250°) and likely were associated with episodic storms. Similar to the wave regime during typhoon season, the wave climate during the period of February–June (outside the typhoon season) was also characterized by frequent (> 30 d per season) and short-period (~ 8 s) trade wind swells with relatively small wave heights (~ 2 m) originating from the east. Infrequent (< 10 d per season) and long-period (12–14 s) swells with slightly larger wave heights (~ 3 m) also occurred during this period and originate from the northwest (~ 330°).

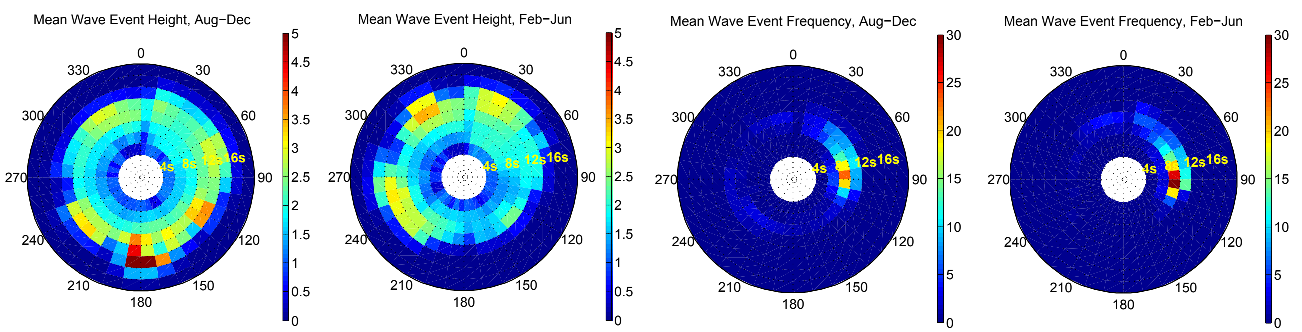


Figure 17.4.3a. NOAA Wave Watch III directional wave climatology for Farallon de Pajaros from January 1997 to May 2008. This climatology was created by binning (6 times daily) significant wave height, dominant period, and dominant direction from a box (1° × 1°) centered on Farallon de Pajaros (20°30′ N, 144°54′ E). Mean significant wave height (*far left and left*), indicated by color scale, for all observations in each directional and frequency bin from August to December (typhoon season) and from February to June. The transition months of January and July are omitted for clarity. Mean number of days (*right and far right*) that conditions in each directional and frequency bin occur in each season, indicated by color scale ; for example, if the color indicates 30, then, on average, the condition occurred during 30 out of 150 days of that season.

17.5 Corals and Coral Disease

17.5.1 Coral Surveys

Coral Cover and Colony Density

From MARAMP 2003 towed-diver surveys, mean cover of live hard corals on forereef habitats around the island of Farallon de Pajaros was 10% (SE 0.9). Coral cover was low in all regions, compared with results from surveys conducted around other islands in the Mariana Archipelago, with the majority (81%) of survey segments exhibiting < 10% live coral cover (Fig. 17.5.1a, top panel). In one segment of a survey conducted in the southeast region, estimates of coral cover were 30%–40%, the highest level observed around this island.

From MARAMP 2005 towed-diver surveys, mean cover of live hard corals on forereef habitats around Farallon de Pajaros was 5% (SE 0.8). Coral cover was low in all regions (Fig. 17.5.1a, middle panel). Towed divers recorded estimates of stressed-coral cover, including corals that were fully bleached (white), pale or discolored, malformed, or stricken with tumors (see Chapter 2: "Methods and Operational Background," Section 2.4.5: "Corals and Coral Disease"). Overall, 2% (SE 1.1) of coral cover observed on forereef habitats around Farallon de Pajaros appeared stressed. This observation of stressed corals was made in the west region during a survey for which estimates of coral cover were 1%–5%.

From MARAMP 2007 towed-diver surveys, mean cover of live hard corals on forereef habitats around Farallon de Pajaros was 5% (SE 0.6). Similar to findings in 2005, coral cover was low in all regions (Fig. 17.5.1a, bottom panel). Overall, 2% (SE 0.8) of coral cover observed on forereef habitats appeared stressed. Two segments with stressed-coral cover > 10% were noted along the exposure of the west and northeast regions; estimates of coral cover for these segments were 1%–10%.

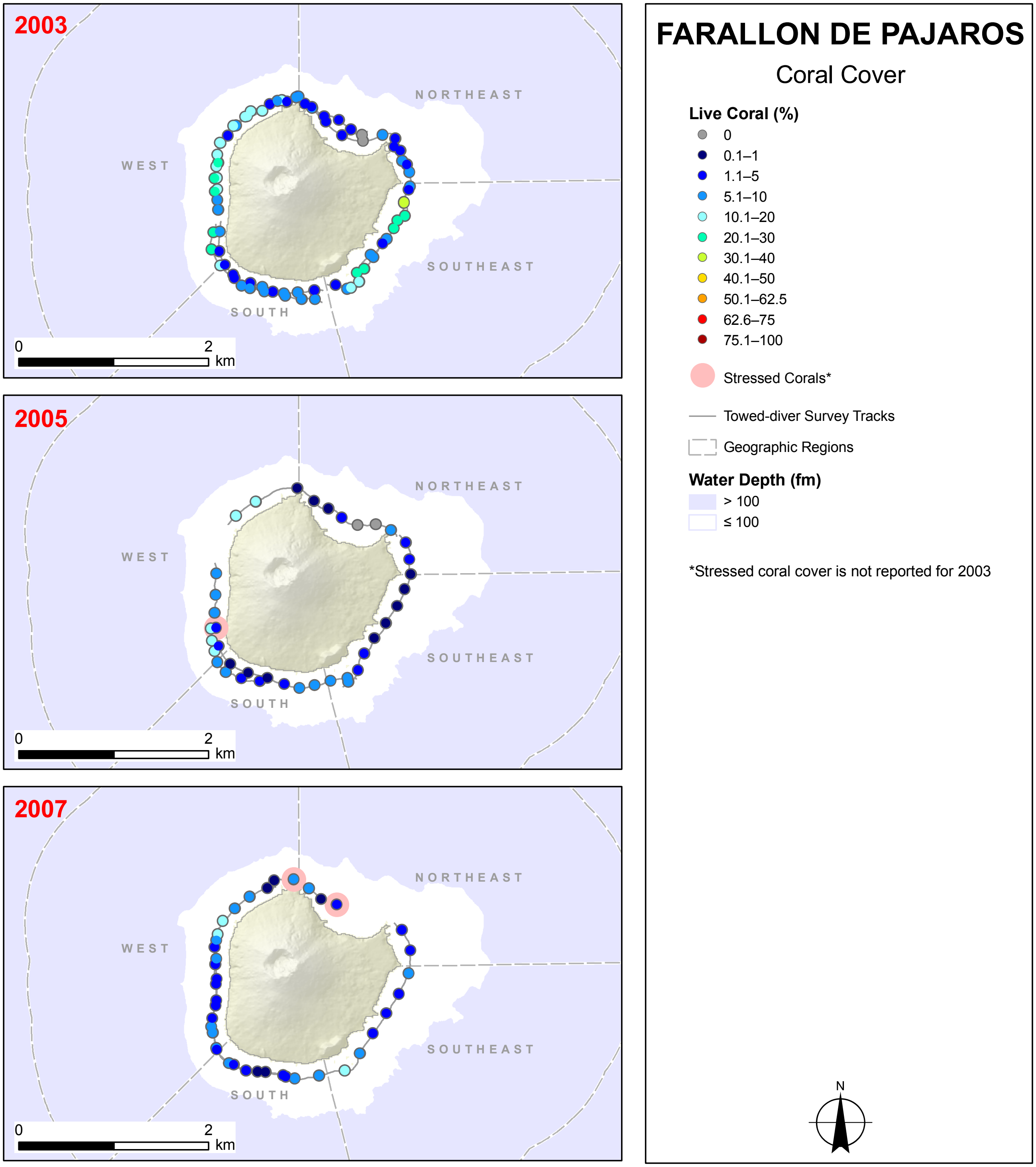


Figure 17.5.1a. Cover (%) observations of live and stressed hard corals from towed-diver benthic surveys of forereef habitats conducted around Farallon de Pajaros during MARAMP 2003, 2005, and 2007. Each colored point represents an estimate of live coral cover over a 5-min observation segment with a survey swath of ~ 200 × 10 m (~ 2000 m^2). Pink symbols represent segments where estimates of stressed-coral cover were > 10%. Stressed-coral cover was measured as a percentage of overall coral cover in 2005 and 2007.

During MARAMP 2003, 2 REA benthic surveys using the quadrat method on forereef habitats at Farallon de Pajaros documented 83 coral colonies within a total survey area of 7.5 m^2. Site-specific colony densities were 10.1 colonies m^{-2} at REA site FDP-02 in the west region and 12.2 colonies m^{-2} at FDP-01 in the southeast region (Fig. 17.5.1b, top panel) with a mean of 11.1 colonies m^{-2} (SE 0.9).

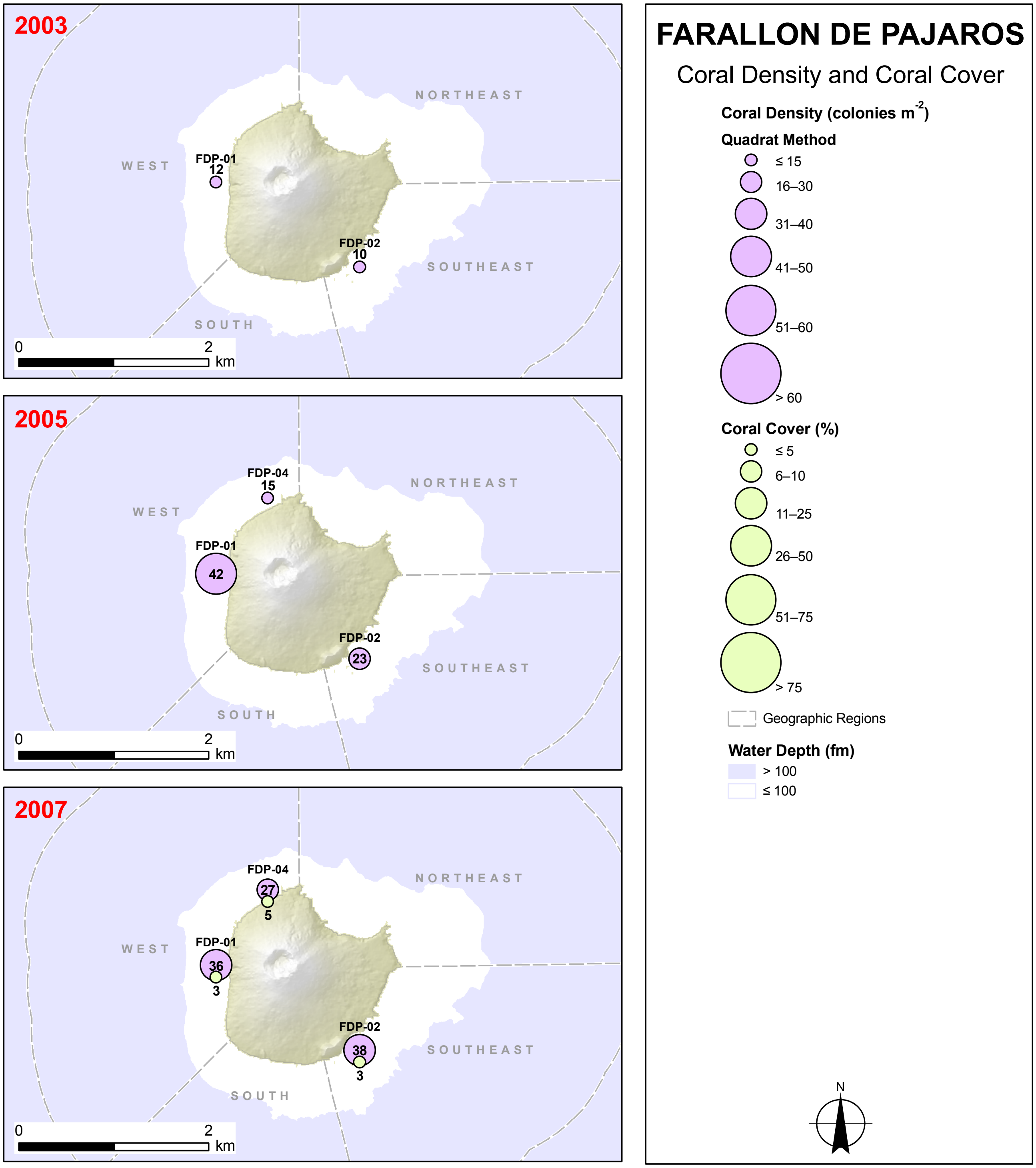


Figure 17.5.1b. Colony-density (colonies m^{-2}) observations of live hard corals from REA benthic surveys of forereef habitats conducted at Farallon de Pajaros during MARAMP 2003, 2005, and 2007 and cover (%) observations of live corals from REA benthic surveys during MARAMP 2007. Values are provided within, above, or below each symbol. The quadrat method was used to assess coral-colony density.

During MARAMP 2005, 3 REA benthic surveys using the quadrat method on forereef habitats at Farallon de Pajaros documented 318 coral colonies within a total survey area of 12 m^2. Site-specific colony density ranged from 14.8 to 41.5 colonies m^{-2} with an overall sample mean of 26.5 colonies m^{-2} (SE 7.9). The highest colony density was recorded at FDP-01 (Fig. 17.5.1b, middle panel).

During MARAMP 2007, 3 REA benthic surveys using the line-point-intercept method were conducted on forereef habitats at Farallon de Pajaros. Site-specific estimates of live-hard-coral cover from these surveys ranged from 2.9% to 4.9% (Fig. 17.5.1b, bottom panel) with an overall sample mean of 3.6% (SE 0.7). Live coral cover was slightly higher at FDP-04 compared to FDP-01 and FDP-02.

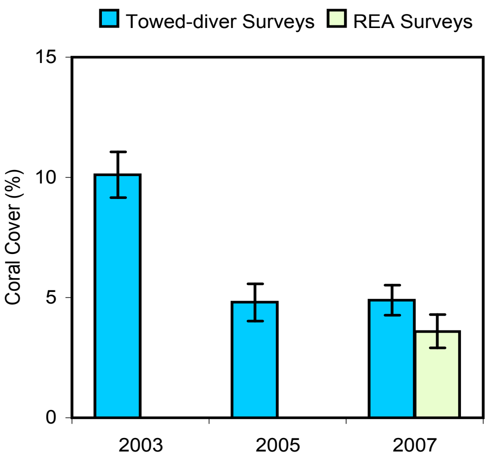


Figure 17.5.1c. Temporal comparison of the mean live coral cover (%) values from REA and towed-diver benthic surveys conducted on forereef habitats around Farallon de Pajaros during MARAMP 2003, 2005, and 2007. No REA surveys using the line-point-intercept method were conducted around Farallon de Pajaros in 2003 and 2005. Error bars indicate standard error (± 1 SE) of the mean.

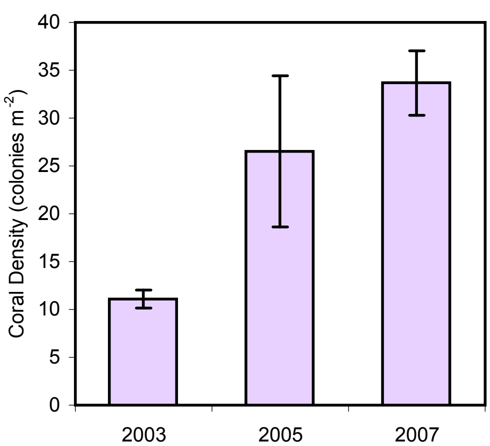


Figure 17.5.1d. Temporal comparison of mean coral-colony densities (colonies m^{-2}) from REA benthic surveys conducted on forereef habitats at Farallon de Pajaros during MARAMP 2003, 2005, and 2007. The quadrat method was used in all 3 years to measure coral-colony density. Error bars indicate standard error (± 1 SE) of the mean.

During MARAMP 2007, 3 REA benthic surveys using the quadrat method on forereef habitats at Farallon de Pajaros documented 404 coral colonies within a total survey area of 12 m^2. Site-specific colony density ranged from 27 to 37.8 colonies m^{-2} with an overall sample mean of 33.7 colonies m^{-2} (SE 3.4). The highest colony density was recorded at FDP-02 (Fig. 17.5.1b, bottom panel).

Islandwide mean cover of live corals, estimated from towed-diver surveys of forereef habitats, varied between MARAMP survey years, ranging from 10% (SE 0.9) in 2003 to 5% (SE 0.8) in 2005 (Fig. 17.5.1c); the estimate in 2007 was also 5% (SE 0.6). The decrease by half in coral cover between 2003 and 2005 does not appear to be a reflection of spatial variation in survey effort between the 2 MARAMP survey years, since the areas with highest coral cover in 2003 were resurveyed in 2005 and 2007. The decline in coral cover between 2003 and 2005 is particularly evident in the southeast and west regions. In each survey year, looking at results by region, the highest level of coral cover was recorded in the west region. Similar to estimates of coral cover from towed-diver surveys conducted at this island in 2007, site-specific estimates of coral cover averaged 3.6% (SE 0.7) for the 3 REA sites surveyed in 2007 (Farallon de Pajaros was not surveyed for coral cover using the line-point-intercept method in 2003 or 2005).

The overall sample mean of coral-colony density from REA benthic surveys of forereef habitats around Farallon de Pajaros increased from 11.1 colonies m^{-2} (SE 0.9) in 2003 to 26.5 colonies m^{-2} (SE 7.9) in 2005 and 33.7 colonies m^{-2} (SE 3.4) in 2007 (Fig. 17.5.1d). The same temporal pattern exists when only the 2 sites surveyed in all 3 years (FDP-01 and FDP-02) are examined: mean density increased from 11.1 colonies m^{-2} (SE 0.9) in 2003 to 32.4 colonies m^{-2} (SE 9.1) in 2005 and 37 colonies m^{-2} (SE 0.8) in 2007. The change in colony density between 2003 and 2007 could reflect increased recruitment, fragmentation of existing colonies, or both.

Coral Generic Richness and Relative Abundance

Two REA benthic surveys of forereef habitats were conducted using the quadrat method at Farallon de Pajaros during MARAMP 2003, and at least 7 coral genera were observed at each site (Fig. 17.5.1e, top panel). Three REA benthic surveys of forereef habitats were conducted using the quadrat method during MARAMP 2005. Generic richness in 2005 ranged from 2 genera at FDP-04 to 13 genera at FDP-01, with an overall mean of 6 (SE 3.5) coral genera per site (Fig. 17.5.1e, middle panel). The same 3 sites were surveyed using the quadrat method during MARAMP 2007. The fewest gen-

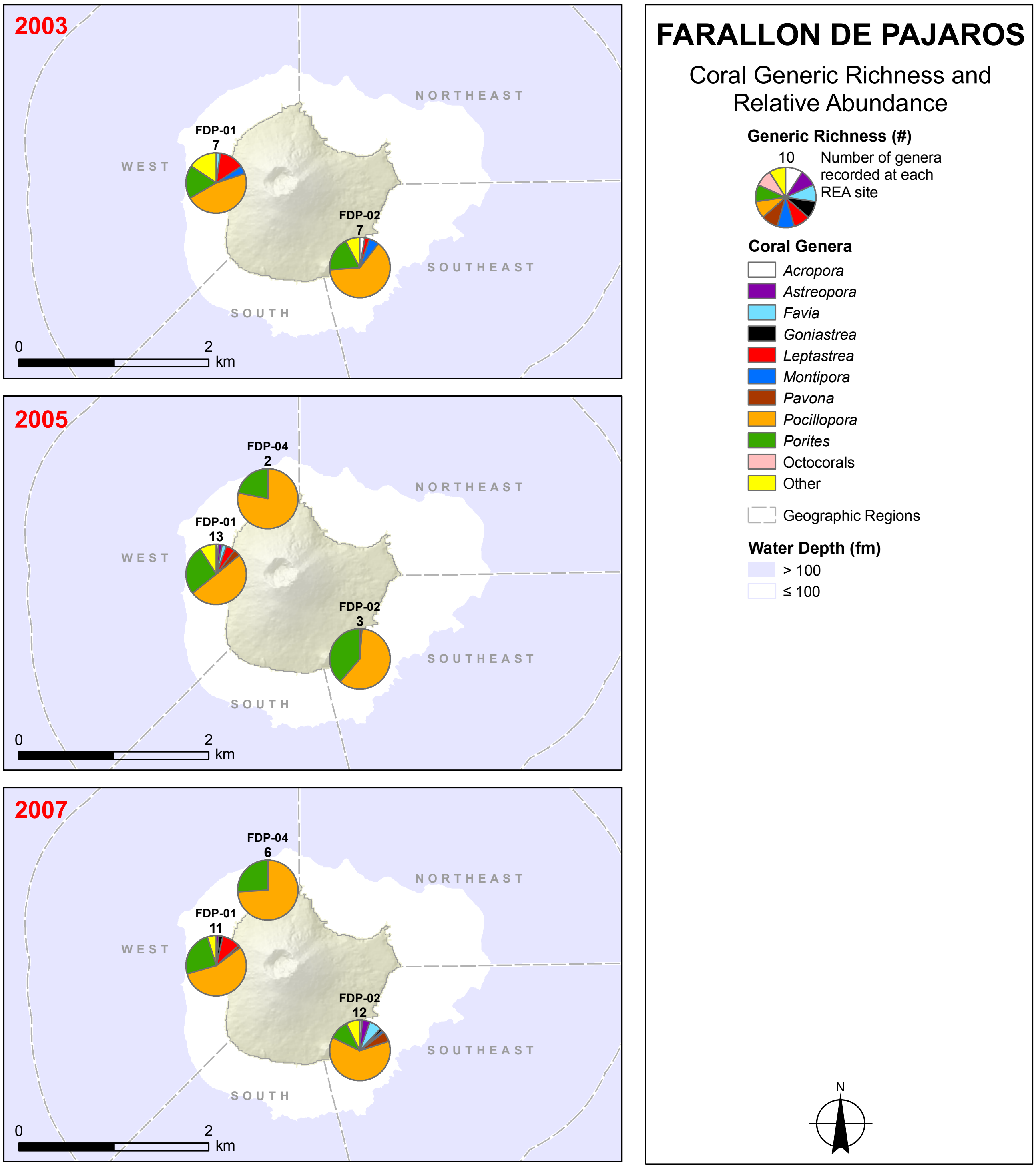


Figure 17.5.1e. Observations of coral generic richness and relative abundance of coral genera from REA benthic surveys of forereef habitats conducted at Farallon de Pajaros during MARAMP 2003, 2005, and 2007. The pie charts indicate percentages of relative abundance of key coral genera. The quadrat method was used in all 3 years to survey coral genera.

era (6) were again found at FDP-04 in 2007, but the most genera (12) were now observed at FDP-02 (Fig. 17.5.1e, bottom panel). This higher number of genera detected at FDP-02 in 2007 (12, compared to 3 in 2005) contributed to an increase in the overall mean to 9.7 (SE 1.9) coral genera per site.

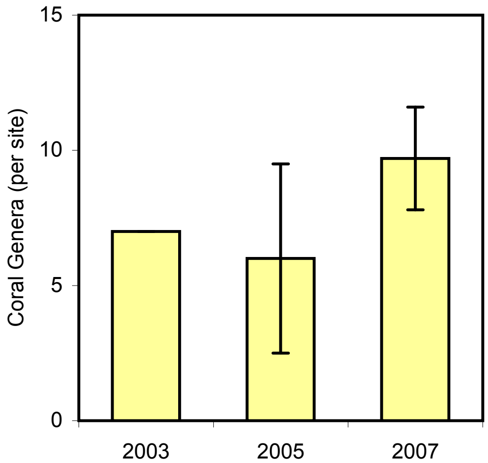


Figure 17.5.1f. Temporal comparison of overall mean numbers of coral genera per site from REA benthic surveys conducted on forereef habitats around Farallon de Pajaros during MARAMP 2003, 2005, and 2007. The quadrat method was used in the 3 years to survey coral genera. Error bars indicate standard error (± 1 SE) of the mean.

The overall sample mean of generic richness on forereef habitats at Farallon de Pajaros was higher in 2007 with 9.7 (SE 1.9) coral genera per site than in 2003 and 2005 with 7 (SE 0) and 6 (SE 3.5) coral genera per site (Fig. 17.5.1f). This change is also seen when only the 2 sites surveyed in all 3 years (FDP-01 and FDP-02) are examined. Mean generic richness for these 2 sites increased from 7 (SE 0) coral genera per site in 2003 to 11.5 (SE 0.5) coral genera per site in 2007. This increase in observed generic richness between 2003 and 2007 resulted from both a greater number of genera being recorded at individual sites and from additional genera being recorded in 2007.

During the 3 MARAMP survey years, 17 coral genera were observed on forereef habitats at this island. *Pocillopora* and *Porites* were the most dominant genera, contributing more than 10% of the total number of colonies enumerated at Farallon de Pajaros in the 3 survey years. *Pocillopora* was the most numerically abundant genus of the coral fauna in all 3 survey years, accounting for 54.9%, 62.7%, and 62.7% of the total number of colonies enumerated in 2003, 2005 and 2007. *Porites* was the second-most numerically abundant taxon in all 3 survey periods, contributing 18.1%, 29.1%, and 19.9% of the total number of colonies in 2003, 2005, and 2007. All other taxa contributed < 10% to the total number of colonies in all 3 MARAMP survey years.

Coral Size-class Distribution

During MARAMP 2003, 2 REA benthic surveys of forereef habitats were conducted at Farallon de Pajaros using the quadrat method. The coral size-class distribution from these surveys shows that the majority (78.6%) of corals had maximum diameters ≤ 5 cm (Fig. 17.5.1g, top panel). The next 3 size classes (6–10, 11–20, and 21–40 cm) accounted for 13%, 7.3%, and 1.1% of colonies recorded. No colonies with maximum diameters > 40 cm were recorded. High proportions of small (≤ 10 cm) colonies were found at the 2 sites surveyed with 91.1% and 92.1% at FDP-01 and FDP-02. The proportions of midsize (11–40 cm) colonies at the same sites were 8.9% and 7.9%.

During MARAMP 2005, 3 REA benthic surveys of forereef habitats were conducted at Farallon de Pajaros using the quadrat method. The coral size-class distribution from these surveys shows that the majority (95%) of corals had maximum diameters ≤ 5 cm (Fig. 17.5.1g, middle panel). The next 2 size classes (6–10 and 11–20 cm) accounted for 3.5% oand 1.5% of colonies recorded. No colonies with maximum diameter > 20 cm were recorded. High proportions of small (≤ 10 cm) colonies were found at all 3 sites surveyed with 100%, 98.9%, and 96.6% at FDP-01, FDP-02, and FDP-04. Correspondingly, low proportions of midsize (11–40 cm) colonies were observed at the same sites: 0%, 1.1%, and 3.4%.

During MARAMP 2007, 3 REA benthic surveys of forereef habitats were conducted at Farallon de Pajaros using the quadrat method. The coral size-class distribution from these surveys shows that the majority (93.3%) of corals had maximum diameters ≤ 5 cm (Fig. 17.5.1g, bottom panel). The next 3 size classes (6–10, 11–20, and 21–40 cm) accounted for 4.8%, 1.7%, and 0.2% of colonies recorded. No colonies with maximum diameter > 40 cm were recorded. High proportions of small (≤ 10 cm) colonies were found at all 3 sites surveyed with 97.9%, 97.4%, and 99.1% at FDP-01, FDP-02, and FDP-04. Correspondingly, low proportions of midsize (11–40 cm) colonies were observed at the same sites: 2.1%, 2.7%, and 0.9%.

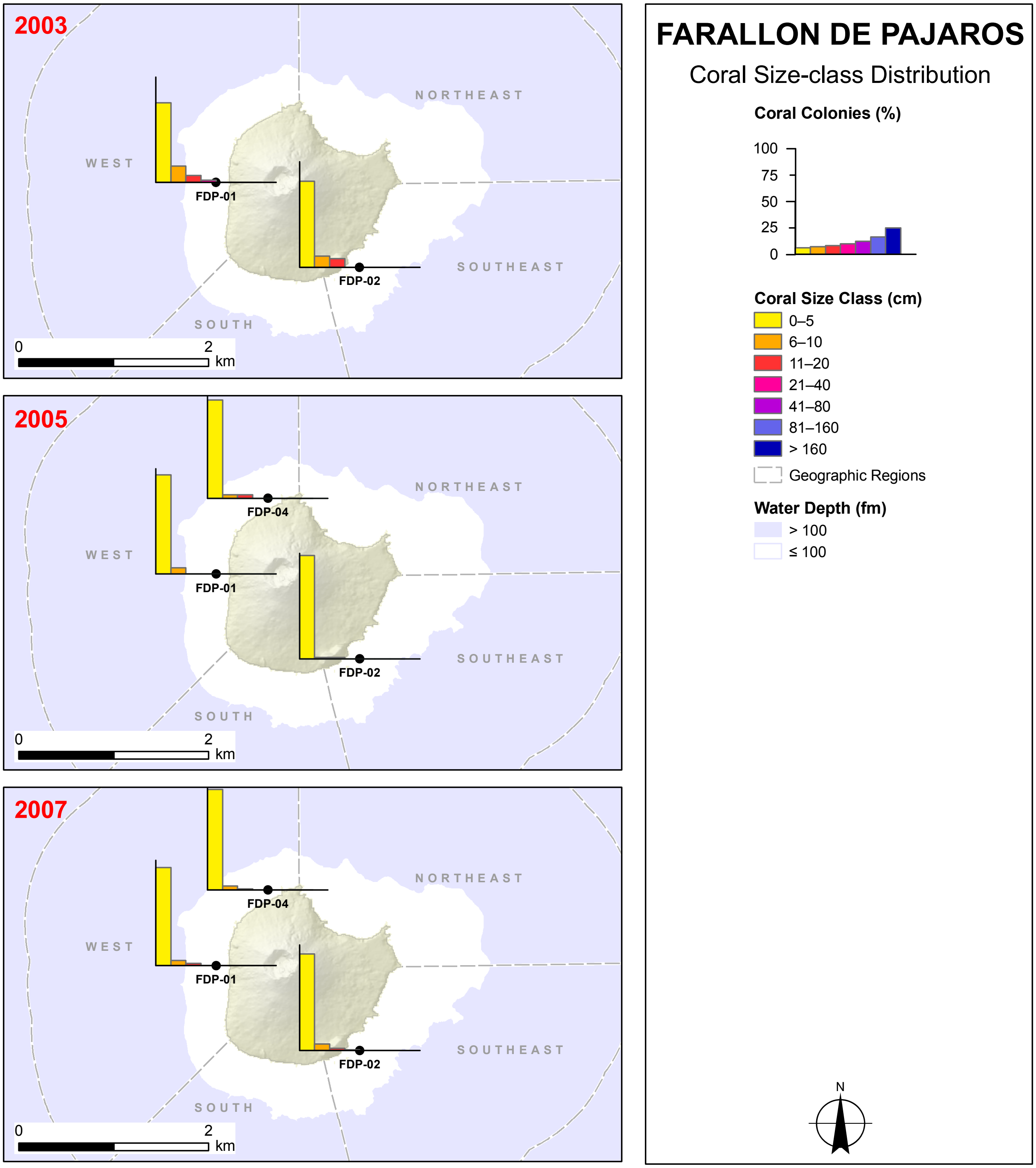
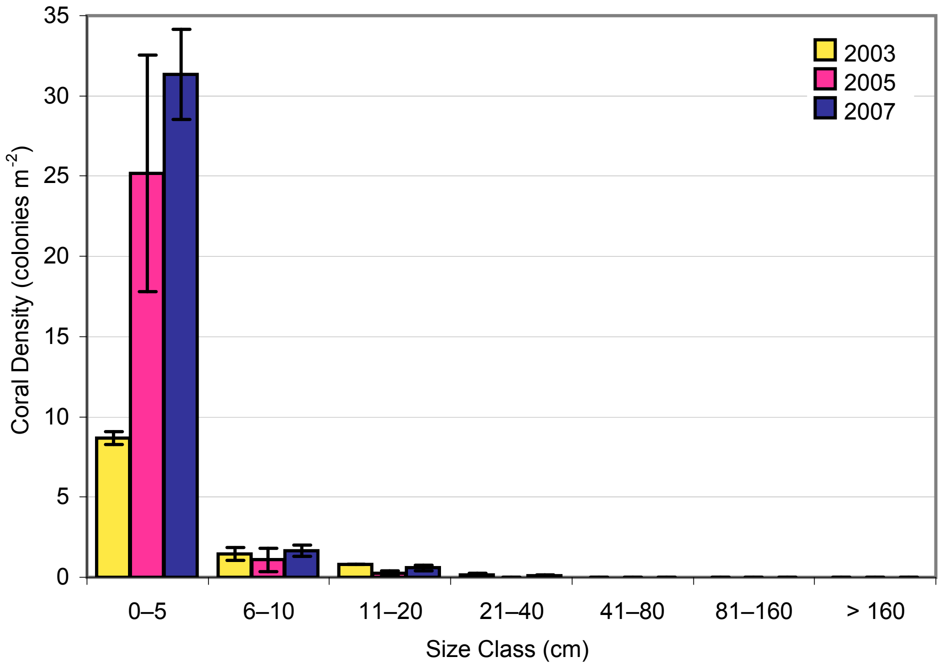


Figure 17.5.1g. Size-class distributions of hard corals from REA benthic surveys of forereef habitats conducted at Farallon de Pajaros during MARAMP 2003, 2005 and 2007. The observed size classes are color coded in a size-frequency chart at each REA site. The quadrat method was used to size corals.

The quadrat method was used to establish size-class distributions on forereef habitats around Farallon de Pajaros during the 3 MARAMP survey periods. Corals whose center fell within the borders of a quadrat (50 × 50 cm) were tallied and measured in 2 planar dimensions to the nearest centimeter. Fewer large colonies than small colonies can fall within a quadrat. This bias can contribute to higher counts of colonies in the smallest size classes and lower counts of colonies in the largest size classes compared to the actual relative colony densities. At each site, 15 or 16 such quadrats were examined (total survey area = 3.75 or 4 m^2), enabling observers to closely inspect and record each coral colony within the quadrat. For more on this survey method, see Chapter 2, "Methods and Operational Background, Section 2.4.5: "Corals and Coral Disease."

In each of the 3 MARAMP survey years, the number of coral colonies in the smallest size class (< 5 cm) was much higher than the number in any of the other size classes (Fig. 17.5.1h). The overall sample mean proportion of colonies censused on forereef habitats at Farallon de Pajaros in the smallest size class increased from 78.6% in 2003 to 95% in 2005, as did the site-specific values for the 2 sites surveyed in both years (FDP-01 and FDP-02). Concordantly, the overall sample mean proportion of colonies in most other size classes decreased between 2003 and 2005, as did many site-specific proportions. This shift towards the smallest size class may reflect recruitment, fragmentation of existing colonies, or both. Minor changes in overall and site-specific size-class distributions between 2005 and 2007 likely reflect chance variation in the placement of individual quadrats.

Figure 17.5.1h. Mean coral-colony density (colonies m^{-2}) by size class from REA benthic surveys of forereef habitats conducted around Farallon de Pajaros during MARAMP 2003, 2005, and 2007. The quadrat method was used in the 3 survey years to size corals. Error bars indicate standard error (± 1 SE) of the mean.



17.5.2 Surveys for Coral Disease and Predation

During MARAMP 2007, REA benthic surveys for coral disease and predation were conducted using the belt-transect method at 3 sites on forereef habitats around Farallon de Parajos, covering a total area of 900 m^2. No cases of coral disease or predation were detected. Farallon de Pajaros was the only island in the Mariana Archipelago to exhibit no coral disease.

17.6 Algae and Algal Disease

17.6.1 Algal Surveys

Algal Cover: Macroalgae and Turf Algae

From MARAMP 2003 towed-diver surveys, mean macroalgal cover on forereef habitats around the island of Farallon de Pajaros was 60% (SE 2.6). Observations of macroalgal cover in 2003 included both macroalgae and turf algae. The survey with the highest mean macroalgal cover of 71%, within a range of 40.1%–100%, occurred in the west region (Fig. 17.6.1a, top left panel). Habitat in this area primarily comprised rock boulders and was classified as medium to medium-high complexity. Similar habitats were found at all survey sites, yet mean values of macroalgal cover were slightly greater on leeward reefs than on windward reefs. The lowest level of macroalgal cover was recorded in the southeast region, where mean macroalgal cover did not fall below 51%.

From MARAMP 2005 towed-diver surveys, mean cover of macroalgae on forereef habitats around Farallon de Pajaros was only 4% (SE 1.3). Mean macroalgal cover was low during all surveys, never exceeding 5%, a level that was recorded in the southeast region (Fig. 17.6.1a, middle left panel). Surveys reported habitat as rock boulders and sand, and habitat complexity was classified predominantly as medium-low to medium.

From MARAMP 2007 towed-diver surveys, mean cover of macroalgae on forereef habitats around Farallon de Pajaros was 3% (SE 0.4). As in 2005, mean macroalgal cover was low during all surveys. The surveys with the highest macroalgae cover of 5%, within a range of 1.1%–10%, occurred in the south and west region (Fig. 17.6.1a, bottom left panel). Surveys reported habitat as rock boulders and sand, and habitat complexity was classified predominantly as medium-high.

During MARAMP 2007, 3 REA benthic surveys of forereef habitats around Farallon de Pajaros were conducted using the line-point-intercept method. No macroalgae were observed during these surveys. At all 3 REA sites surveyed in 2007, total algal cover was made up entirely of turf algae. Turf-algal cover ranged from 85.3% to 95.1% with an overall sample mean of 90% (SE 2.9). The survey with the highest turf-algal cover occurred in the west region at FDP-04 (Fig. 17.6.1b). Relatively high values of turf-algal cover also were recorded in the southeast region with 85.3% at FDP-02 and in the west region with 88.2% at FDP-01.

Algal Cover: Crustose Coralline Red Algae

From MARAMP 2003 towed-diver surveys, mean cover of crustose coralline red algae on forereef habitats around Farallon de Pajaros was 3% (SE 0.8). The survey with the highest mean crustose-coralline-red-algal cover of 10%, within a range of 0%–40%, occurred in the west region (Fig. 17.6.1a, top right panel). All other surveys reported relatively low values of 0%–4% for cover of crustose coralline red algae.

From MARAMP 2005 towed-diver surveys, mean cover of crustose coralline red algae on forereef habitats around Farallon de Pajaros was 8% (SE 1.5). Similar to survey results in 2003, the survey with the highest mean crustose-coralline-red-algal cover of 10%, within a range of 0%–40%, occurred in the west region (Fig. 17.6.1a, middle right panel). Mean cover values of 14% and 15% were observed in areas the along eastern and western coasts. No crustose coralline red algae were observed on northern and southern coasts.

From MARAMP 2007 towed-diver surveys, mean cover of crustose coralline red algae on forereef habitats around Farallon de Pajaros was 5% (SE 0.8). The surveys with the highest mean crustose-coralline-red-algal cover of 10%, within a range of 5.1%–20%, occurred in the west and south regions (Fig. 17.6.1a, bottom right panel). All other surveys reported relatively low values of 0%–4% for cover of crustose coralline red algae. Mean cover in both the northeast and southeast region was < 2%.

During MARAMP 2007, 3 REA benthic surveys of forereef habitats around Farallon de Pajaros were conducted using the line-point-intercept method. No crustose coralline red algae were observed during these surveys (Fig. 17.6.1b).

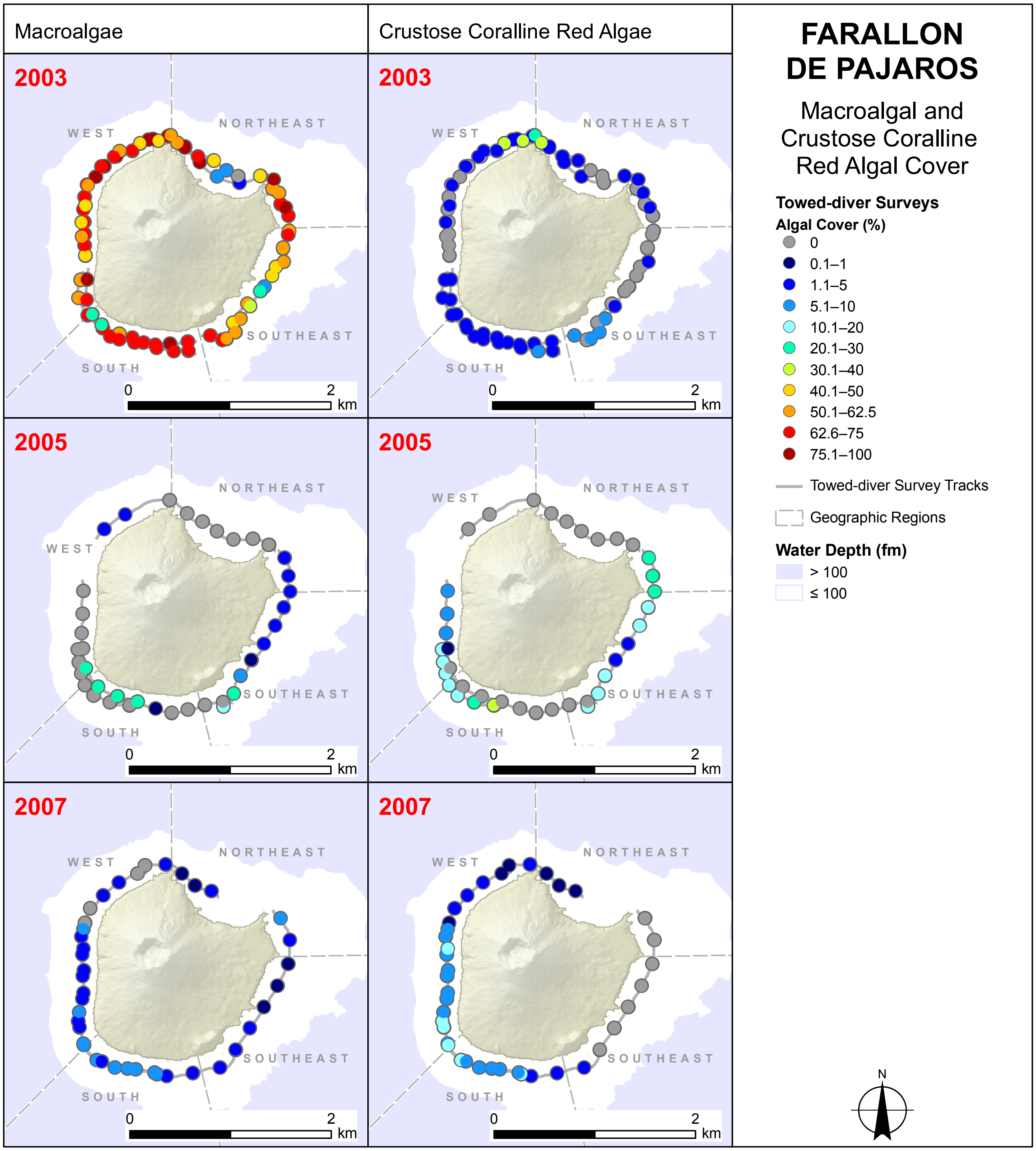


Figure 17.6.1a. Cover (%) observations for macroalgae and crustose coralline red algae from towed-diver benthic surveys of forereef habitats conducted around Farallon de Pajaros during MARAMP 2003, 2005, and 2007. Each large, colored point represents an estimate over a 5-min observation segment with a survey swath of ~ 200 × 10 m (~ 2000 m²). The 2003 macroalgal panel shows observations of both macroalgae and turf algae (towed-diver surveys included turf algae only during MARAMP 2003).

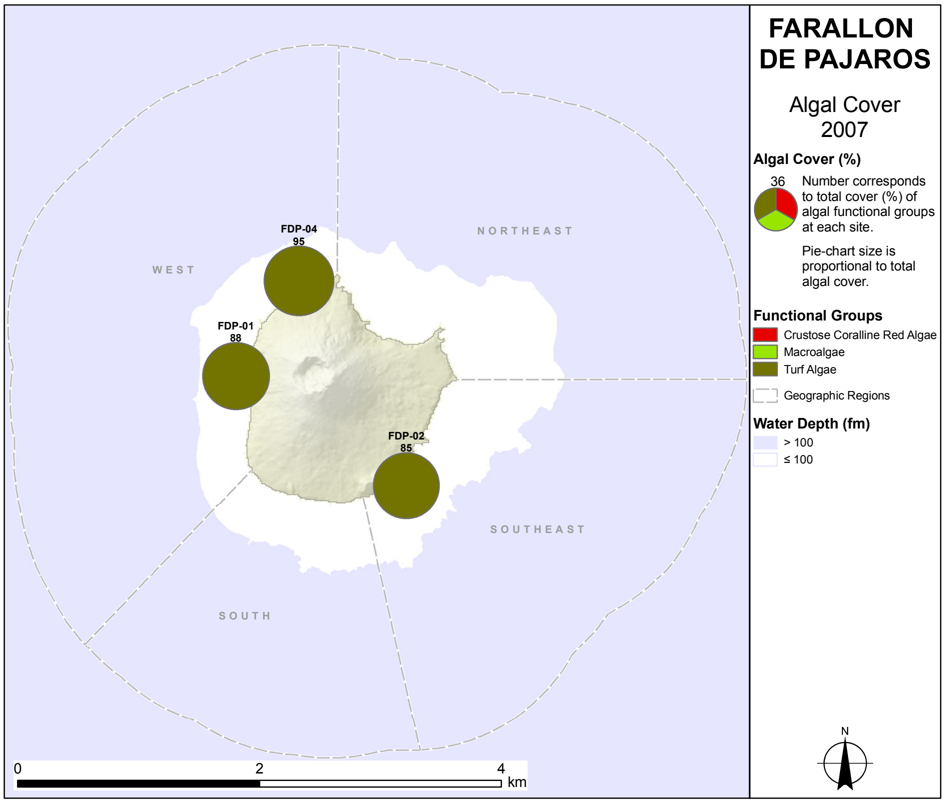


Figure 17.6.1b. Observations of algal cover (%) from REA benthic surveys of forereef habitats conducted using the line-point-intercept method around Farallon de Pajaros during MARAMP 2007. The pie charts indicate algal cover by functional group, and values of total algal cover are provided above each symbol.

Algal Cover: Temporal Comparison

Between MARAMP 2005 and 2007, islandwide mean cover of macroalgal populations around Farallon de Pajaros, based on towed-diver surveys of forereef habitats, essentially remained the same (Fig. 17.6.1c). When considering results, keep in mind that turf algae were included, along with macroalgae, in towed-diver surveys of macroalgal cover only in 2003. Other factors, such as a change in season between survey periods, could have contributed to differences in algal cover (for information about data limitations, see Chapter 2: "Methods and Operational Background," Section 2.4: "Reef Surveys"). Macroalgal cover decreased slightly from MARAMP 2005 to 2007 for some survey areas, particularly for east-facing reefs, but increased slightly between survey periods in the northeast region and along the west and south coasts.

Crustose-coralline-red-algal populations around Farallon de Pajaros, based on towed-diver surveys of forereef habitats, varied as much as 5% in average cover of the benthos between MARAMP survey years. The primary reason for the 5% increase in overall mean cover of crustose coralline red algae between MARAMP 2003 and 2005 was the observation of higher cover values along the east- and west-facing reefs in 2005 than in 2003. Crustose-coralline-red-algal cover values for the north- and south-facing reefs were all < 1% in 2005. Overall cover values decreased between MARAMP 2005 and 2007, particularly in surveys conducted in the northeast and southeast regions. Cover values in the west region decreased by 6%.

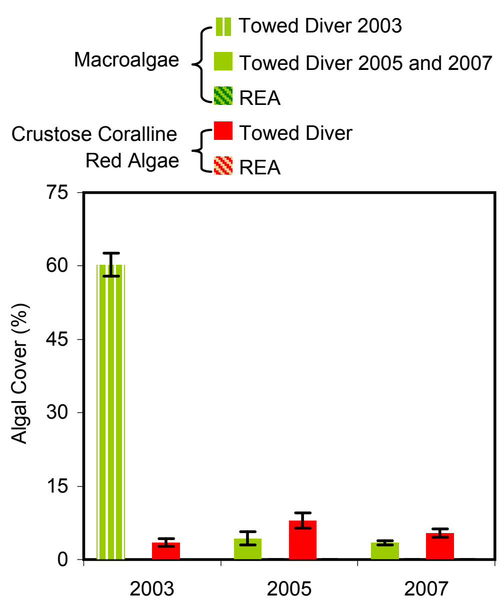


Figure 17.6.1c. Temporal comparison of algal-cover (%) values from surveys conducted on forereef habitats at Farallon de Pajaros during MARAMP 2003, 2005, and 2007. Values of macroalgal cover from towed-diver surveys include turf algae only in 2003. No REA surveys using the line-point-intercept method were conducted around Farallon de Pajaros in 2003 and 2005. Error bars indicate standard error (± 1 SE) of the mean.

Macroalgal Genera and Functional Groups

In the field, because of their small size or similarity in appearance, turf algae, crustose coralline red algae, cyanophytes (blue-green algae), and branched, nongeniculate coralline red algae were lumped into functional group categories. The generic names of macroalgae from field observations are tentative, since microscopic analysis is necessary for proper taxonomic identification. The lengthy process of laboratory-based taxonomic identification of all algal species collected at REA sites is about 90% complete for the northern islands of the Mariana Archipelago with hundreds of species identified so far. Ultimately, based on this microscopic analysis, the generic names of macroalgae reported in this section may change and algal diversity reported for each REA site likely will increase.

During MARAMP 2003, REA benthic surveys were conducted at 4 sites on forereef habitats around Farallon de Pajaros. In the field, 7 macroalgal genera (4 green and 3 brown), containing at least 7 species, as well as 2 additional algal functional groups—turf algae and crustose coralline red algae—were observed in the field. FDP-02 in the southeast region had the highest macroalgal generic diversity with 6 genera, containing 6 species, documented in the field. The lowest macroalgal generic diversity was found at FDP-01 with only turf algae and no macroalgae recorded.

The brown algal genus *Lobophora* was the most common component of the algal communities found around Farallon de Pajaros in 2003, observed in 35.4% of total sampled photoquadrats with 50% occurrence at FDP-02 and 91.7% occurrence at FDP-04 (Fig. 17.6.1d, top panel). *Lobophora* was the only genus to have > 17% occurrence at any site surveyed during MARAMP 2003. Of the remaining 6 taxa tentatively identified, none were observed at more than 1 of the 4 sites, making distinctive spatial patterns of distribution difficult to determine for most macroalgae around Farallon de Pajaros.

Turf algae were common in 2003, occurring in 75% of photoquadrats sampled around Farallon de Pajaros (Fig. 17.6.1d, top panel). The only site where turf algae were missing was FDP-03; however, no other algal functional group was recorded at that site. Crustose coralline red algae were common only at site FDP-04 in the north region, occurring in 41.7% of sampled photoquadrats, and sparse at site FDP-02, occurring in 8.3% of sampled photoquadrats. No cyanobacteria were observed in 2003.

During MARAMP 2005, REA benthic surveys were conducted at 3 sites on forereef habitats around Farallon de Pajaros. In the field, 5 macroalgal genera (1 red, 2 green, and 2 brown), containing at least 5 species, as well as 1 additional algal functional group—turf algae—were observed in the field. FDP-01 and FDP-04, located in the west and northwest regions, had the highest macroalgal generic diversity with 4 genera, each containing 4 species, documented in the field. The lowest macroalgal generic diversity was found in the southeast region at FDP-02 with 3 species representing 3 genera recorded.

Species of *Lobophora* and the red algal genus *Jania* were common at every site surveyed around Farallon de Pajaros in 2005, occurring in 77.8%, and 44.4% of sampled photoquadrats (Fig. 17.6.1d, middle panel). *Lobophora*, found in 75%–83% of photoquadrats sampled, was the dominant macroalgal genus at all sites; however, no distinct spatial pattern was observed. Species of *Jania* occurred in 33% of sampled photoquadrats at FDP-01 and FDP-04, both located in the west region, and in 67% of sampled photoquadrats at FDP-02 in the southeast region. Species of the green algal genera *Dictyosphaeria* and *Rhipidosiphon* were documented in low occurrence (< 17%) at 2 sites each; however, no distinct spatial pattern was observed.

Turf algae were abundant in 2005, occurring in 89% of photoquadrats sampled around Farallon de Pajaros (Fig. 17.6.1d, middle panel). Turf algae were ubiquitous around this island, but no distinct spatial pattern of distribution was observed for turf-algal assemblages at Farallon de Pajaros. No crustose coralline red algae and cyanobacteria were recorded in 2005.

During MARAMP 2007, REA benthic surveys were conducted at 3 sites on forereef habitats around Farallon de Pajaros. In the field, 8 macroalgal genera (2 red, 4 green, and 2 brown), containing at least 8 species, as well as 3 additional algal functional groups—turf algae, crustose coralline red algae, and cyanophytes—were observed in the field. FDP-02 in the southeast region had the highest macroalgal generic diversity with 8 genera, containing 8 species, documented in the field. The lowest macroalgal generic diversity was found at FDP-01 with 4 species representing 4 genera recorded.

Lobophora was the dominant macroalgal genus around Farallon de Pajaros in 2007, occurring in 94.4% of sampled photoquadrats within a range of 83%–100% (Fig. 17.6.1d, bottom panel). Species of the genus *Jania* also abundant at all sites, were found in 91.7%, within a range of 75%–100% ,of photoquadrats sampled at this island. No distinct spatial pattern of distribution was documented for either genus. Species of *Dictyosphaeria* and the brown algal genus *Padina* were documented at all 3 sites surveyed in 2007, occurring in 25% and 13.9% of all sampled photoquadrats. At the genus level, 4 of the 8 taxa tentatively identified occurred only at 1 or 2 sites, making distinctive spatial patterns of distribution difficult to determine for most macroalgae around Farallon de Pajaros. For species occurring across all sites, no distinct spatial patterns were documented, possibly in part because of the low number of sites surveyed at this island and the relatively small geographical area encompassed by this island.

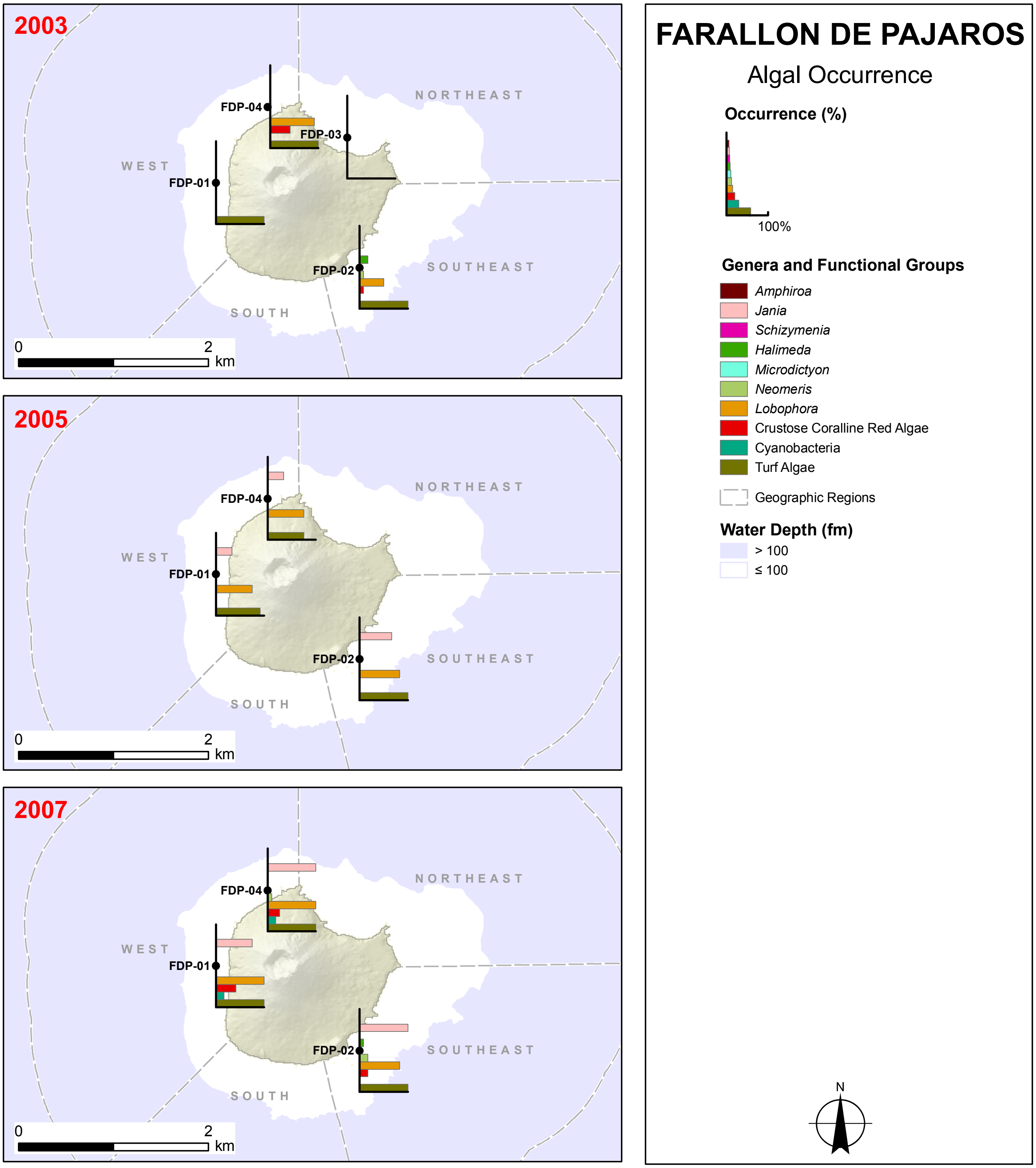


Figure 17.6.1d. Observations of occurrence (%) for select macroalgal genera and algal functional groups from REA benthic surveys of forereef habitats conducted around Farallon de Pajaros during MARAMP 2003, 2005, and 2007. Occurrence is equivalent to the percentage of photoquadrats in which an algal genus or functional group was observed. The length of the x-axis denotes 100% occurrence.

Turf algae occurred in 100% of photoquadrats sampled around Farallon de Pajaros in 2007 (Fig. 17.6.1d, bottom panel). Communities of crustose coralline red algae were common at all sites, occurring in 41.7%, 16.7%, and 25% of photoquadrats at FDP-01, FDP-02, and FDP-04. Cyanobacteria, observed only at 2 of the 3 REA sites surveyed, were found in 16.7% of photoquadrats sampled at those sites.

No distinct pattern of changes in the number of macroalgal genera was recorded. The overall occurrence of macroalgal genera did not fluctuate greatly, varying by 5%–8%, between 2003, 2005, and 2007 (Fig. 17.6.1e). The percentages of sampled photoquadrats in which species of *Dictyosphaeria, Jania,* and *Lobophora* were found increased between survey years. The genus *Lobophora* consistently had the highest occurrence levels during each of the 3 survey years with average values ranging from 35.4% to 94.4%. *Jania,* found in 0%–91.7% of sampled photoquadrats, was the second-most prevalent genus, followed by *Dictyosphaeria*, occurring in 0%–25% of sampled photoquadrats.

Crustose coralline red algae occurred in 0%–27.8%, and cyanobacteria in 0%–11%, of photoquadrats sampled at Farallon de Pajaros during MARAMP 2003, 2005, and 2007. No patterns of changes in the abundance of these functional groups were obvious. Turf algae occurred in 75% of sampled photoquadrats in 2003 and in 88.9% in 2005 and 100% in 2007.

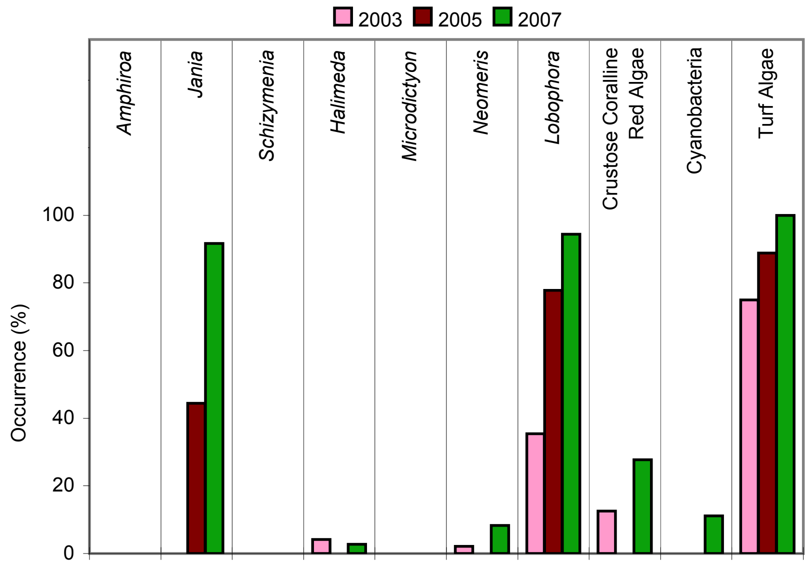


Figure 17.6.1e. Temporal comparison of occurrence (%) values from REA benthic surveys of algal genera and functional groups conducted on forereef habitats around Farallon de Pajaros during MARAMP 2003, 2005, and 2007.

17.6.2 Surveys for Coralline-algal Disease

During MARAMP 2007, REA benthic surveys for coralline-algal-disease were conducted in concert with coral-disease assessments at 3 sites at Farallon de Pajaros. No cases of coralline-algal disease were detected.

17.7 Benthic Macroinvertebrates

17.7.1 Benthic Macroinvertebrates Surveys

Four groups of benthic macroinvertebrates—sea urchins, sea cucumbers, giant clams, and crown-of-thorn seastars (COTS)—were monitored on forereef habitats around the island of Farallon de Pajaros through REA and towed-diver benthic surveys during MARAMP 2003, 2005, and 2007. This section describes by group the results of these surveys. A list of additional taxa observed during REA invertebrate surveys is provided in Chapter 3: “Archipelagic Comparisons.”

Monitoring these 4 groups of ecologically and economically important taxa provides insight into the population distribution, community structure, and habitats of the coral reef ecosystems of the Mariana Archipelago. High densities of the corallivorous COTS can affect greatly the community structure of reef ecosystems. Giant clams are filter feeders that are sought after in the Indo-Pacific for their meat, which is considered a delicacy, and for their shells. Sea cucumbers, sand-producing detritus foragers, are harvested for food. Sea urchins are important algal grazers and bioeroders.

In 2003, 8 towed-diver surveys were conducted around Farallon de Pajaros, and, in both 2005 and 2007, 4 towed-diver surveys were performed. In each of these survey years, 3 REA surveys were done. When considering survey results from towed-diver surveys, keep in mind that cryptic or small organisms can be difficult for divers to see, so the density values presented in this report, especially of giant clams and sea urchins, may under-represent the number of individuals present.

Overall, both the REA and towed-diver surveys suggested extremely low daytime macroinvertebrate abundance on forereef habitats around Farallon de Pajaros compared to other areas surveyed in the Mariana Archipelago. Minor fluctuations in observed densities between MARAMP survey periods occurred with half of the target groups. Temporal patterns of islandwide mean benthic macroinvertebrate density around Farallon de Pajaros—from towed-diver benthic surveys during MARAMP 2003, 2005, and 2007—are also shown in this section (Figs. 17.1b and f).

Giant Clams

During MARAMP 2003, species of *Tridacna* giant clams were observed at 1 of the 3 REA sites surveyed and in 2 of the 8 towed-diver surveys conducted around Farallon de Pajaros (Fig. 17.7.1a, top panel). REA site FDP-02 had a giant-clam density of 4 organisms 100 m^{-2}. Islandwide mean density from towed-diver surveys was 0.004 organisms 100 m^{-2} (SE 0.002). Giant clams were observed only during 2 towed-diver surveys and only in survey segments in the south region Between these 2 towed-diver surveys completed around the southwestern shore, one had the higher mean density of giant clams with 0.022 organisms 100 m^{-2}; segment densities from this survey ranged from 0 to 0.089 organisms 100 m^{-2}.

During MARAMP 2005, no giant clams were observed at the 3 REA sites surveyed around Farallon de Pajaros, but 1 of the 4 towed-diver surveys had recordings of giant clams (Fig. 17.7.1a, middle panel), with an islandwide mean of 0.001 organisms 100 m^{-2} (SE 0.001). The single towed-diver survey with observations of giant clams was completed in the southeast region. The mean density of giant clams from this survey was 0.005 organisms 100 m^{-2}; segment densities ranged from 0 to 0.053 organisms 100 m^{-2}.

During MARAMP 2007, giant clams were observed at 2 of the 3 REA sites surveyed and in 3 of the 4 towed-diver surveys conducted around Farallon de Pajaros (Fig. 17.7.1a, bottom panel). The overall sample mean density of giant clams from REA surveys was 0.555 organisms 100 m^{-2} (SE 0.4), and the islandwide mean density from towed-diver surveys was 0.013 organisms 100 m^{-2} (SE 0.004). Survey results suggest giant clams were most abundant at FDP-02 in the southeast region with a density of 1.33 organisms 100 m^{-2}. Among all towed-diver surveys around this island, the survey completed in the south region had the highest mean density of giant clams with 0.036 organisms 100 m^{-2}; segment densities for this survey ranged from 0 to 0.107 organisms 100 m^{-2}.

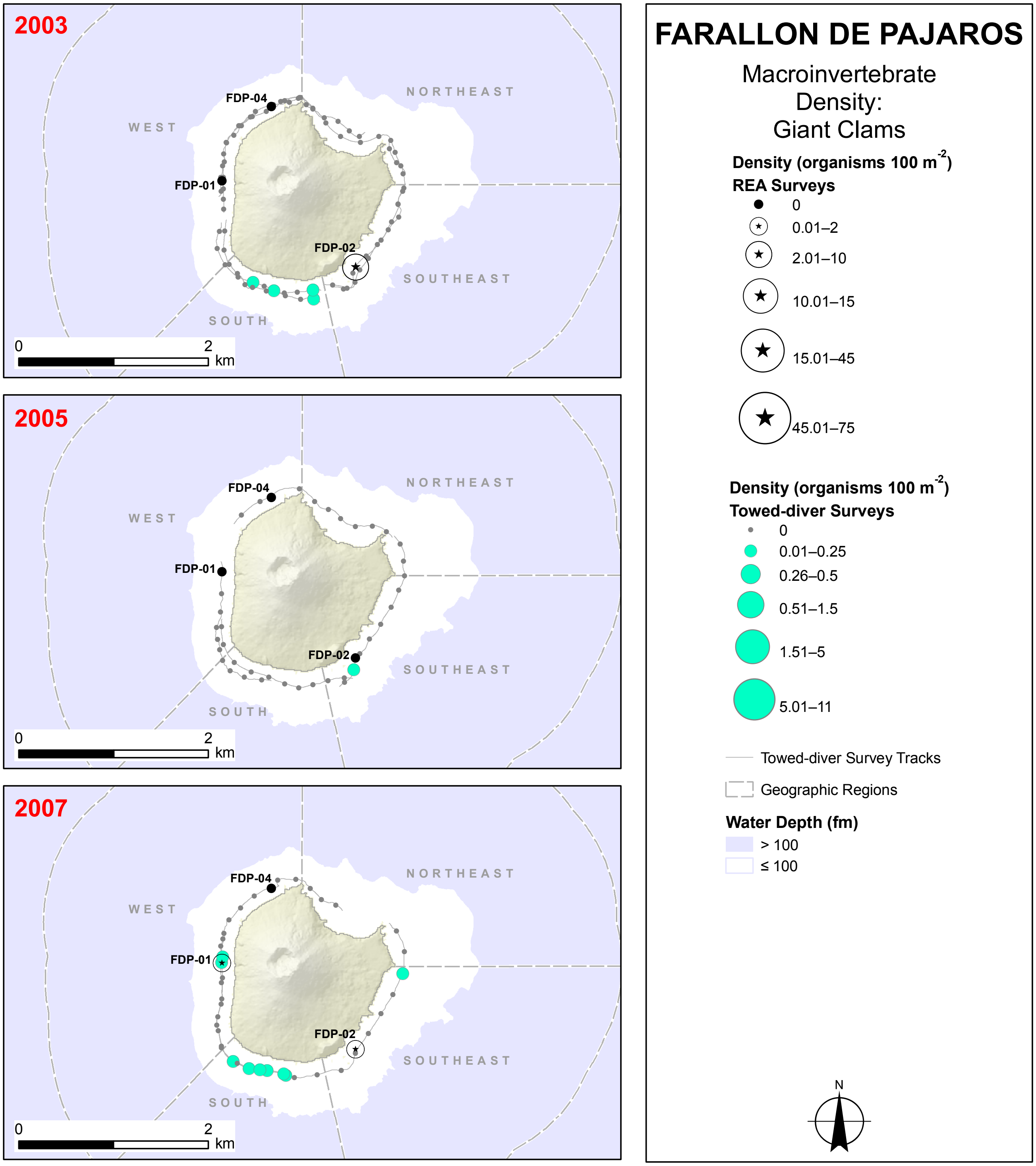


Figure 17.7.1a. Densities (organisms 100 m^{-2}) of giant clams from REA and towed-diver benthic surveys of forereef habitats conducted around Farallon de Pajaros during MARAMP 2003, 2005, and 2007.

Towed-diver benthic surveys suggested low abundance of giant clams around Farallon de Pajaros during the 3 MARAMP survey periods, relative to the rest of the Mariana Archipelago. The south region had the most giant clams during each of the 3 survey years. The overall observed mean density of giant clams around Farallon de Pajaros was higher in 2007 than in 2003 and 2005 (Fig. 17.7.1b). Minor fluctuations in densities are not necessarily indicative of changes in the population structure of giant clams (for information about data limitations, see Chapter 2: "Methods and Operational Background," Section 2.4: "Reef Surveys").

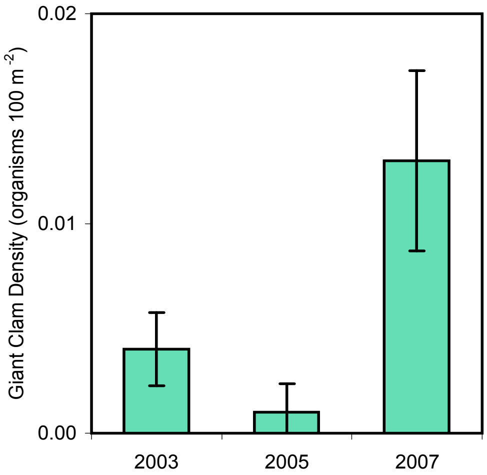


Figure 17.7.1b. Temporal comparison of mean densities (organisms 100 m^{-2}) of giant clams from towed-diver benthic surveys conducted on forereef habitats around Farallon de Pajaros during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.

Crown-of-thorns Seastars

No crown-of-thorns seastars were observed at the REA sites surveyed or during towed-diver surveys conducted around Farallon de Pajaros during MARAMP 2003, 2005, and 2007.

Sea Cucumbers

No sea cucumbers were observed at the REA sites surveyed or during towed-diver surveys conducted around Farallon de Pajaros during MARAMP 2003, 2005, and 2007.

Sea Urchins

During MARAMP 2003, sea urchins were observed at all 3 REA sites surveyed and in 5 of the 8 towed-diver surveys conducted around Farallon de Pajaros (Fig. 17.7.1c, top panel). The overall sample mean density of sea urchins from REA surveys was 55 organisms 100 m^{-2} (SE 51.5), and the islandwide mean density from towed-diver surveys was 1.06 organisms 100 m^{-2} (SE 0.48). Survey results suggest that sea urchins were most abundant at FDP-02 in the southeast region with 158 organisms 100 m^{-2}; rock-boring urchins accounted for 99% of all urchin observations at this site. Rock-boring urchins from the genus *Echinostrephus* were the dominant macroinvertebrates at all sites, accounting for 96.3% of all recorded urchins. The other genera observed in low numbers at REA sites included *Echinometra* and *Echinothrix*. Among all towed-diver surveys around Farallon de Pajaros, one of the surveys completed in the southeast region had the greatest mean density of 6.52 organisms 100 m^{-2}; segment densities ranged from 0 to 28.63 organisms 100 m^{-2}.

During MARAMP 2005, sea urchins were observed at 1 of the 3 REA sites surveyed and in 3 of the 4 towed-diver surveys conducted around Farallon de Pajaros (Fig. 17.7.1c, middle panel). REA site FDP-01 had a sea-urchin density of 4 organisms 100 m^{-2}. Observed species were from the rock-boring genus *Echinostrephus* and from the genus *Diadema*. The islandwide mean density of sea urchins from towed-diver surveys was 3.71 organisms 100 m^{-2} (SE 1.36). Among all towed-diver surveys around Farallon de Pajaros, the survey completed in the southeast region had the highest mean density of 12.21 organisms 100 m^{-2}; segment densities from this survey ranged from 0 to 39.69 organisms 100 m^{-2}. The second-highest mean density of sea urchins from a towed-diver survey was 2.26 organisms 100 m^{-2} survey, recorded along the southern shoreline; segment densities ranged from 0 to 10.57 organisms 100 m^{-2}.

During MARAMP 2007, sea urchins were observed at 1 of the 3 REA sites surveyed and in 3 of the 4 towed-diver surveys conducted around Farallon de Pajaros (Fig. 17.7.1c, bottom panel). REA site FDP-02 had a sea-urchin density of 54 organisms 100 m^{-2}. All but one of the observed urchins were recorded as species from the rock-boring urchin genus *Echinostrephus*. The islandwide mean density of sea urchins from towed-diver surveys was 1.98 organisms 100 m^{-2} (SE 0.9). Among all towed-diver surveys around Farallon de Pajaros, the survey completed along the southeastern shore had the highest mean density of 7.86 organisms 100 m^{-2}; segment densities from this survey ranged from 0 to 29.20 organisms 100 m^{-2}.

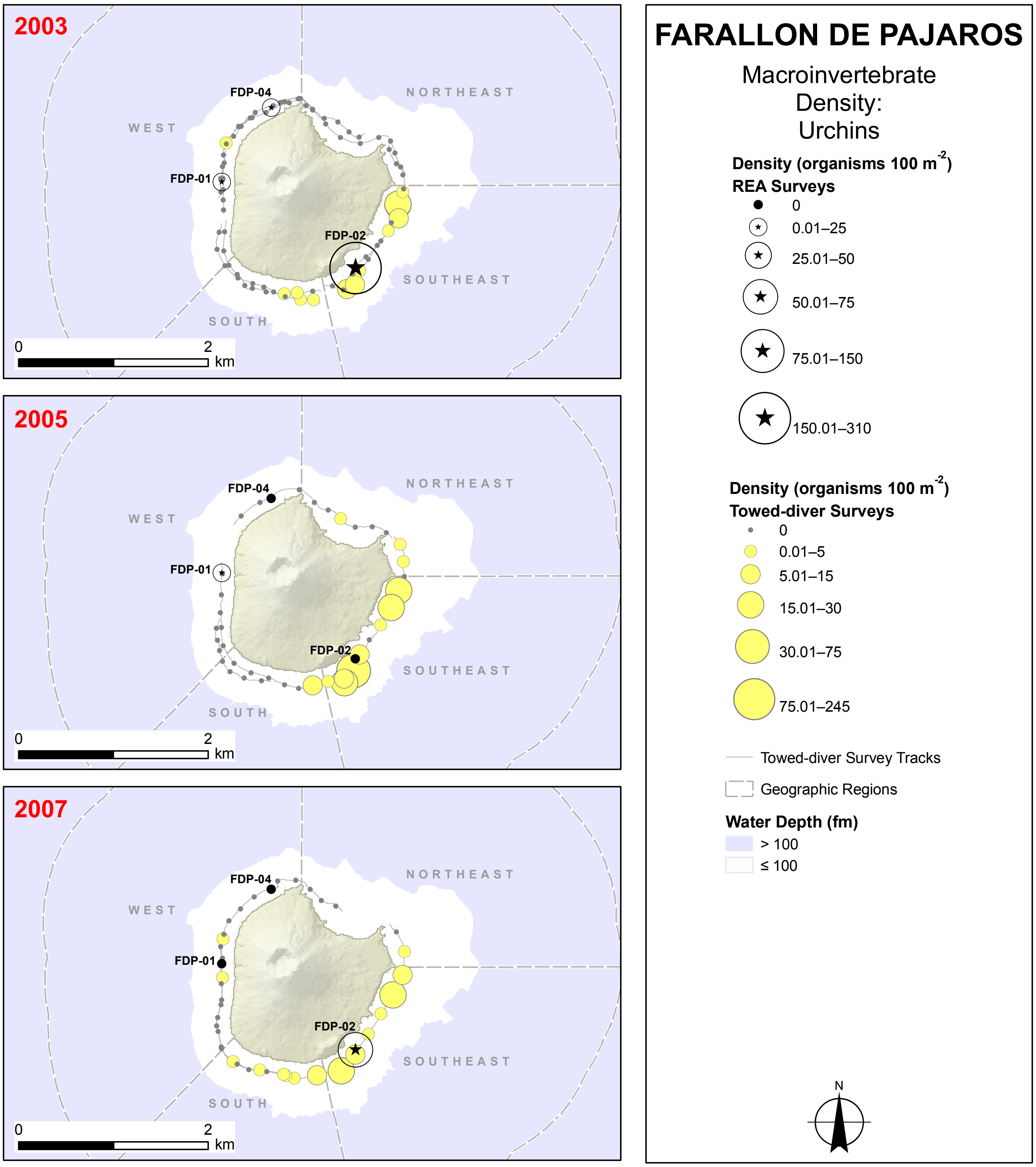


Figure 17.7.1c. Densities (organisms 100 m-²) of sea urchins from REA and towed-diver benthic surveys of forereef habitats conducted around Farallon de Pajaros during MARAMP 2003, 2005, and 2007.

With the exception of the southeastern shoreline, towed-diver surveys suggested low daytime abundance of sea urchins around Farallon de Pajaros during MARAMP 2003, 2005, and 2007, compared to the rest of the Mariana Archipelago. The overall observed mean density of sea urchins was lower in 2003 than in 2005 and 2007 (Fig. 17.7.1d). Fluctuations in densities are not necessarily indicative of changes in the population structure of sea urchins (for information about data limitations, see Chapter 2: "Methods and Operational Background," Section 2.4: "Reef Surveys"). Although sea urchins were not recorded down to the genus level during towed-diver surveys, REA surveys suggested that more than 96% of the sea urchin species observed around Farallon de Pajaros were rock-boring urchins from the genus *Echinostrephus.*

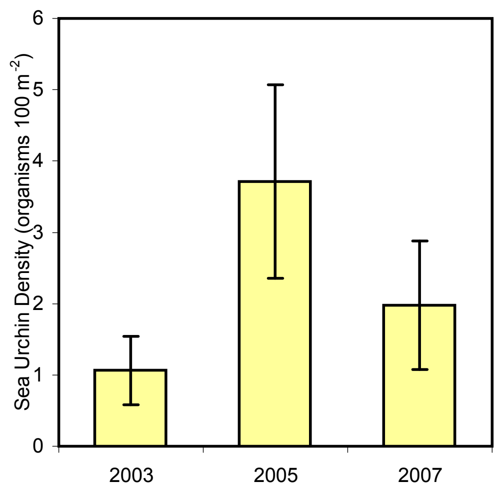


Figure 17.7.1d. Temporal comparison of mean densities (organisms m^{-2}) of sea urchins from towed-diver benthic surveys conducted on forereef habitats around Farallon de Pajaros during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.

17.8 Reef Fishes

17.8.1 Reef Fish Surveys

Large-fish Biomass

During MARAMP 2003, 8 towed-diver surveys for large fishes (≥ 50 cm in total length [TL]) were conducted in forereef habitats around the island of Farallon de Pajaros. The islandwide estimated mean biomass of large fishes, calculated as weight per unit area, was 3.24 kg 100 m^{-2} (SE 0.52), a moderate level compared to other survey areas in the Mariana Archipelago. Observed mean biomass was heterogeneous around this island with the highest values in the west region and along the north shore, where sharks and jacks were common (Fig. 17.8.1a, top panel). Jacks (Carangidae), snappers (Lutjanidae), reef sharks (Carcharhinidae), and nurse sharks (Ginglymostomatidae) together accounted for 82% or 2.67 kg 100 m^{-2} of islandwide mean large-fish biomass. Sharks accounted for the greatest proportion (34%) of the overall biomass of large fishes. Around this island, 82 sharks were observed, and the most common species was the grey reef shark (*Carcharhinus amblyrhynchos*) and whitetip reef shark (*Triaenodon obesus*).

During MARAMP 2005, 4 towed-diver surveys for large fishes (≥ 50 cm in TL) were conducted in forereef habitats around Farallon de Pajaros. The islandwide estimated mean biomass of large fishes was 0.20 kg 100 m^{-2} (SE 0.08), a low value compared to results from surveys completed in 2003. Low biomass and numerical densities were observed in all regions around this island (Fig. 17.8.1a, middle panel). Although large-fish biomass estimates were low in 2005, jacks, snappers, and reef sharks contributed 89% or 0.18 kg 100 m^{-2} of the islandwide biomass of large fishes. Only 3 sharks were observed, all of them whitetip reef sharks.

During MARAMP 2007, 4 towed-diver surveys for large fishes (≥ 50 cm in TL) were conducted in forereef habitats around Farallon de Pajaros. The islandwide estimated mean biomass of large fishes was 2.21 kg 100 m^{-2} (SE 0.61), higher than the level recorded in 2005 and similar to the value observed in 2003. Observed values of large-fish biomass were similar in all areas around this island (Fig. 17.8.1a, bottom panel). Consistent with previous years, sharks, snappers, and jacks accounted for 84% or 1.87 kg 100 m^{-2} of large-fish mean biomass for this island. Around this island, 20 sharks were observed, accounting for the largest proportion (47%) of overall large-fish biomass.

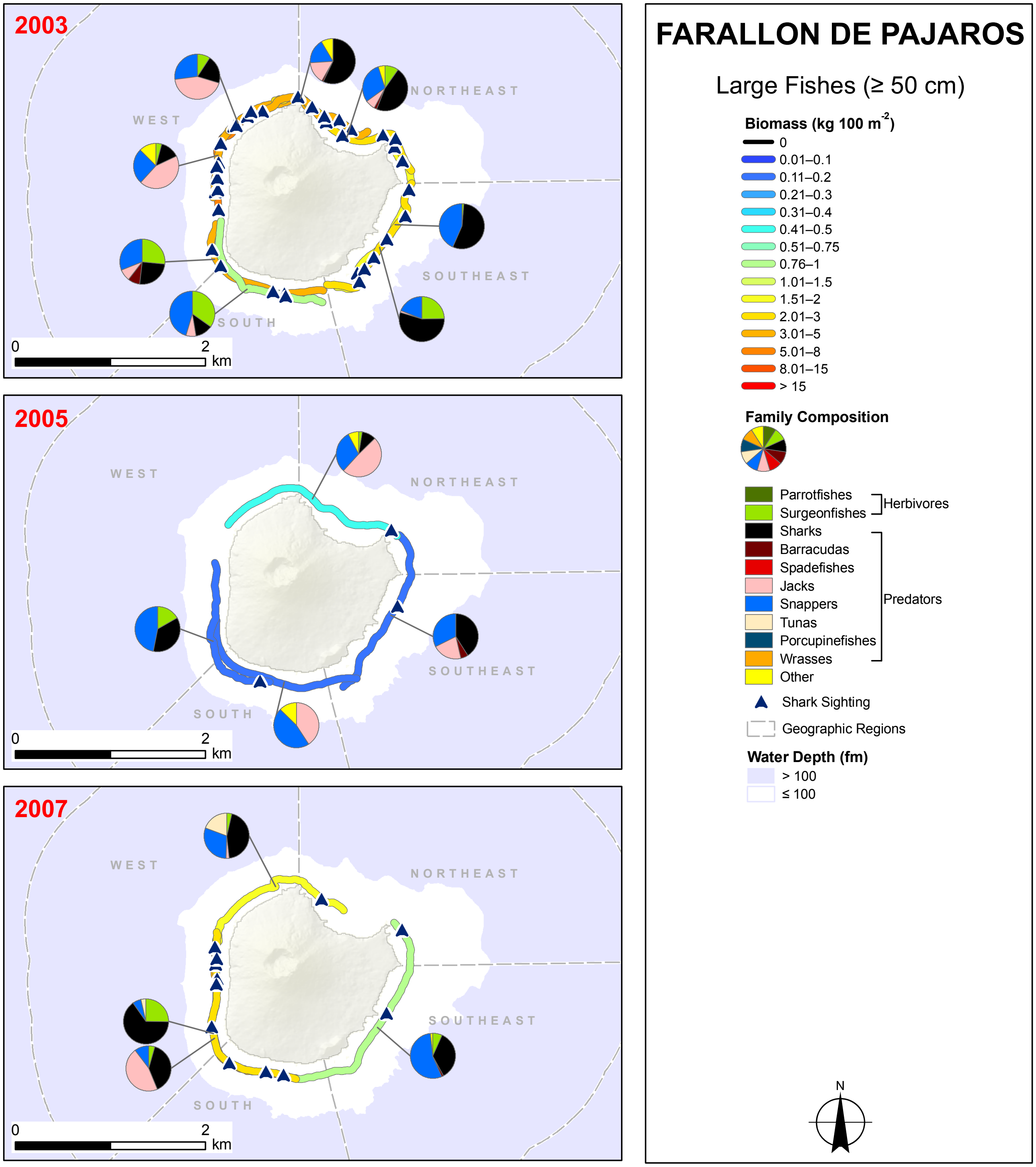


Figure 17.8.1a. Observations of large-fish (≥ 50 cm in TL) biomass (kg 100 m^{-2}), family composition, and individual shark sightings from towed-diver fish surveys of forereef habitats conducted around Farallon de Pajaros during MARAMP 2003, 2005, and 2007. Each blue triangle represents a sighting of one or more sharks recorded inside or outside of the survey area over which it is shown.

In general, for the 3 MARAMP survey periods, the highest values of large-fish biomass from towed-diver surveys of forereef habitats were recorded in the west region. Observed large-fish biomass was surprisingly low in 2005, compared to results from surveys conducted in 2003 and 2007 (Fig. 17.8.1b). For each of the 3 survey periods, sharks, jacks, and snappers composed the largest proportions of islandwide mean large-fish biomass. Most remarkable were observations made in 2007, when reef sharks alone contributed 47% of overall biomass of large fishes. Also notable were sightings of the rare giant grouper (*Epinephelus lanceolatus*) in 2003 and sightings of numerous large twinspot snappers (*Lutjanus bohar*), black and white snappers (*Macolor niger*), and midnight snappers (*Macolor macularis*) during each of the 3 survey periods.

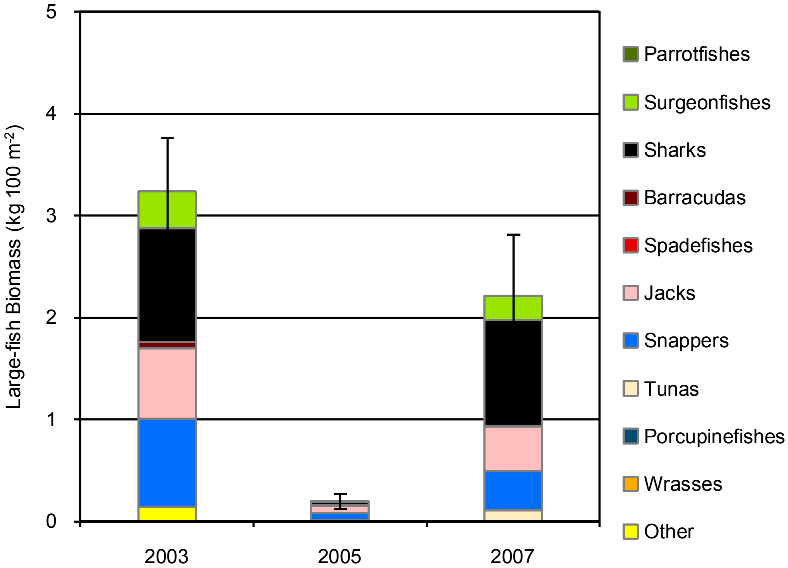


Figure 17.8.1b. Temporal comparison of mean values of large-fish (≥ 50 cm in TL) biomass (kg 100 m^{-2}) from towed-diver fish surveys of forereef habitats conducted around Farallon de Pajaros during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.

Total Fish Biomass and Species Richness

Total fish biomass for the 4 REA sites surveyed in forereef habitats at Farallon de Pajaros during MARAMP 2003 was high, compared to other sites in the Mariana Archipelago, with an overall sample mean of 16.17 kg 100 m^{-2} (SE 9.89). The highest biomass of 45.10 kg 100 m^{-2} was observed at REA site FDP-01 in the west region, and the lowest biomass of 0.48 kg 100 m^{-2} was found at FDP-03 (Fig. 17.8.1c, top panel). Reef sharks accounted for the largest proportion (39%) or 6.36 kg 100 m^{-2} of total fish biomass for this island. Snappers were also common, contributing 24% of overall total fish biomass. Over half of the total fish biomass at FDP-01 was comprised of sharks, primarily the grey reef shark.

Based on REA surveys conducted during MARAMP 2003, species richness at Farallon de Pajaros was extremely variable with a range of 5–51 species 100 m^{-2}. The highest diversity was seen at FDP-01 in the west region (Fig. 17.8.1c, top panel). Surgeonfishes (Acanthuridae) composed the most abundant family. Recent recruitment of orangespine unicornfishes (*Naso lituratus*) contributed to the rank of this species as the most abundant species observed.

Total fish biomass for the 3 REA sites surveyed in forereef habitats at Farallon de Pajaros during MARAMP 2005 was precipitously lower than estimates from 2003 with an overall sample mean of 6.77 kg 100 m^{-2} (SE 2.18). The highest biomass was observed at FDP-04 in the west region (Fig. 17.8.1c, middle panel). Surgeonfishes accounted for the largest proportion (40%) or 2.69 kg 100 m^{-2} of total fish biomass for this island. The orangeband surgeonfish (*Acanthurus olivaceus*) and orangespine unicornfish were the most dominant surgeonfishes by weight. Medium to large-bodied fishes, such as sharks, jacks (Carangidae), and groupers (Serranidae), were infrequently encountered during this survey period.

Based on REA surveys conducted in MARAMP 2005, species richness at Farallon de Pajaros was moderate with a range of 24–30 species 100 m^{-2} and lower than both observations made at this island in 2003 and estimates made for the Mariana Archipelago. The highest diversity was observed at FDP-01 in the west region (Fig. 17.8.1c, middle panel). Damselfishes (Pomacentridae) and wrasses (Labridae) composed the most abundant families. The midget chromis (*Chromis acares*) was the most abundant damselfish species, and the ornate wrasse (*Halichoeres ornatissimus*) was the most abundant wrasse species.

Total fish biomass for the 3 REA sites surveyed in forereef habitats at Farallon de Pajaros during MARAMP 2007 was high, compared to estimates from 2003 and 2005, with an overall sample mean of 15.77 kg 100 m^{-2} (SE 6.54). Consistent with results from MARAMP 2003 and 2005, the highest biomass for this island was observed in the west region (Fig. 17.8.1c, bottom panel). Surgeonfishes accounted for the largest proportion (37%) or 5.84 kg 100 m^{-2} of total fish biomass for this island. Fusiliers (Caesionidae) and snappers (Lutjanidae) were also common, contributing 16% and 12% of overall total fish biomass. No sharks were observed during REA surveys in 2007.

Based on REA surveys conducted in 2007, species richness at Farallon de Pajaros was moderate with a range of 29–34 species 100 m^{-2}. The highest diversity was observed at FDP-02 in the southeast region (Fig. 17.8.1c, bottom panel). Damselfishes composed the most abundant family with Vanderbilt's chromis (*Chromis vanderbilti*) and midget chromis being the 2 most abundant species.

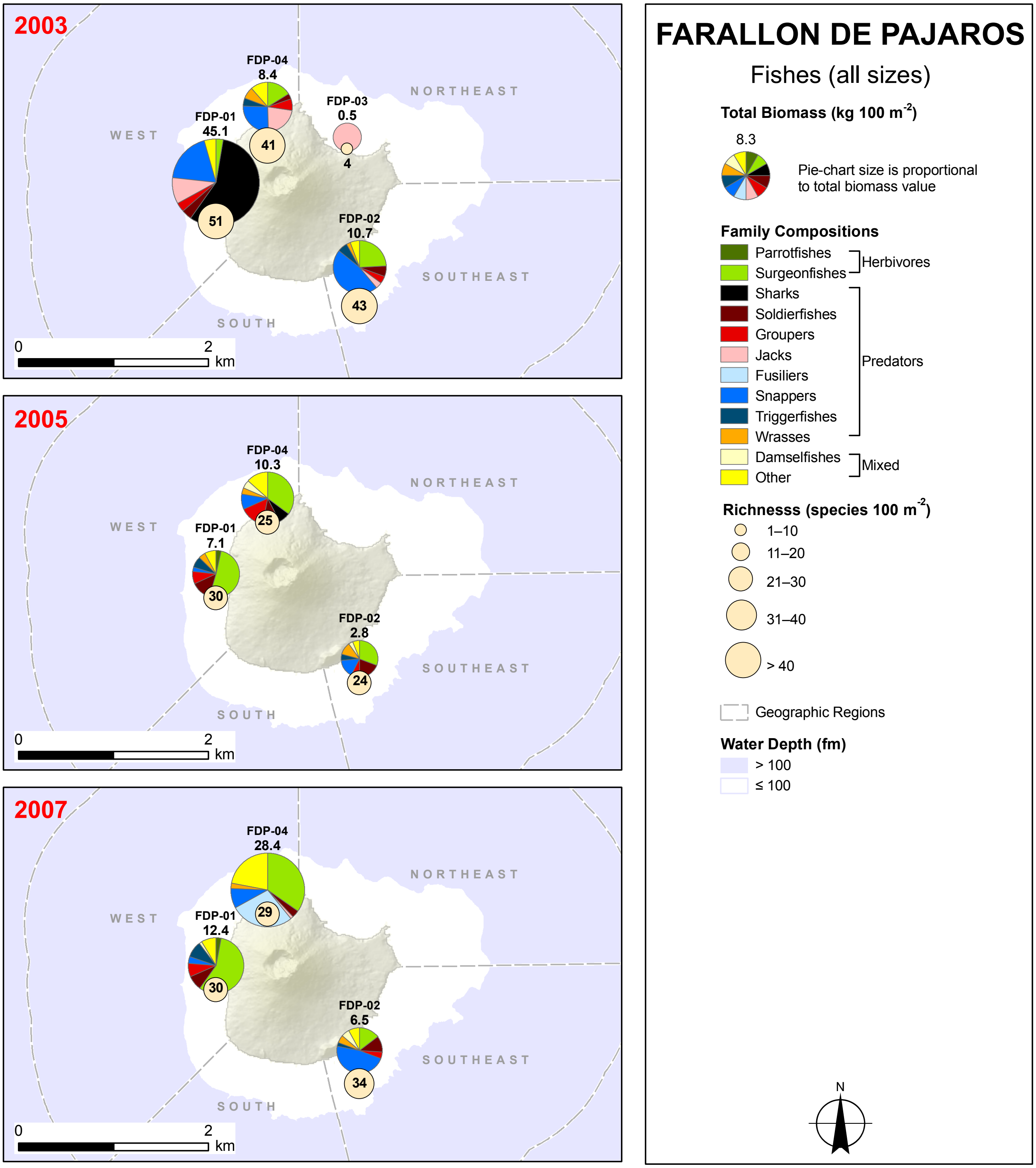


Figure 17.8.1c. Observations of total fish biomass (all species and size classes in kg 100 m^{-2}), family composition, and species richness (species 100 m^{-2}) from REA fish surveys using the belt-transect method in forereef habitats at Farallon de Pajaros during MARAMP 2003, 2005, and 2007.

REA surveys conducted during all 3 MARAMP survey periods showed the west region to have the highest mean value of total fish biomass. Survey results for overall total fish biomass were similar in 2003 and 2007 (Fig. 17.8.1d). In 2003, reef sharks composed 39% or 6.36 kg 100 m^{-2} of the overall total fish biomass observed at Farallon de Pajaros. Surgeonfishes, specifically the orangeband surgeonfish and the orangespine unicornfish, were also abundant and contributed substantially to overall biomass during each survey period.

The highest species richness was observed in 2003 with 51 species 100 m^{-2} at FDP-01 in the west region. Species richness for other sites and during subsequent years averaged 30 species 100 m^{-2}.

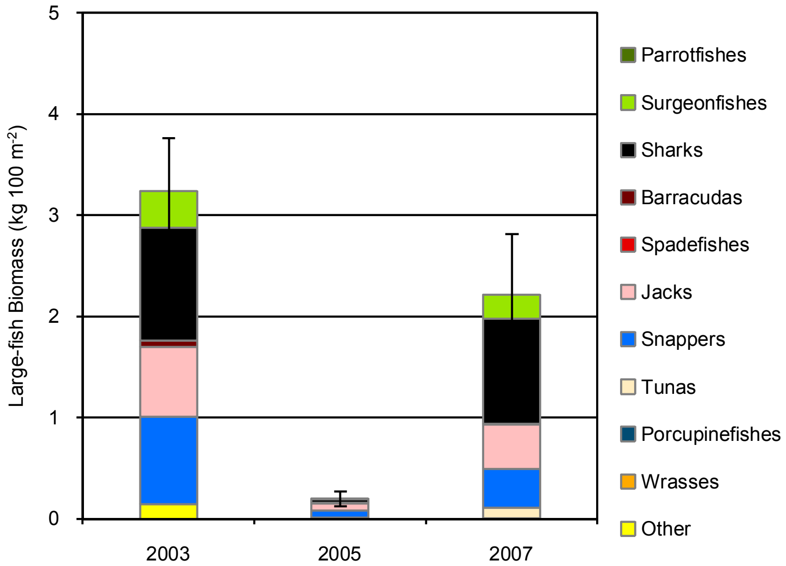


Figure 17.8.1d. Temporal comparison of mean values of total fish biomass (all species and size classes in kg 100 m^{-2}) from REA fish surveys of forereef habitats conducted at Farallon de Pajaros during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.

17.9 Marine Debris

17.9.1 Marine Debris Surveys

During MARAMP 2003, no sightings of marine debris were recorded in the 8 towed-diver surveys conducted on forereef habitats around Farallon de Pajaros (Fig. 17.9.1a, top panel). In the 4 towed-diver surveys conducted during MARAMP 2005 on forereef habitats around this island, 4 sightings of derelict fishing gear were documented (Fig. 17.9.1a, middle panel). All 4 of these observations were of old fishing lines near the border between the south and west regions. During MARAMP 2007, 2 sightings of derelict fishing gear were recorded in the 4 towed-diver surveys conducted on forereef habitats around Farallon de Pajaros (Fig. 17.9.1a, bottom panel). Both of these observations were of old fishing lines and, similar to results seen in 2005, were made at the border between the south and west regions. No munitions, wrecks, or other man-made objects were identified during any of the 3 MARAMP survey years.

Observations of debris are positive identifications, but absence of reports does not imply lack of debris. Since methods for observing marine debris varied between MARAMP surveys in 2003, 2005, and 2007, temporal comparisons are not appropriate. Debris sightings were recorded differently—with sightings in 2003 recorded as a direct part of diver observational methods and sightings in 2005 and 2007 recorded solely as incidental observations by the towed divers in their observer comments.

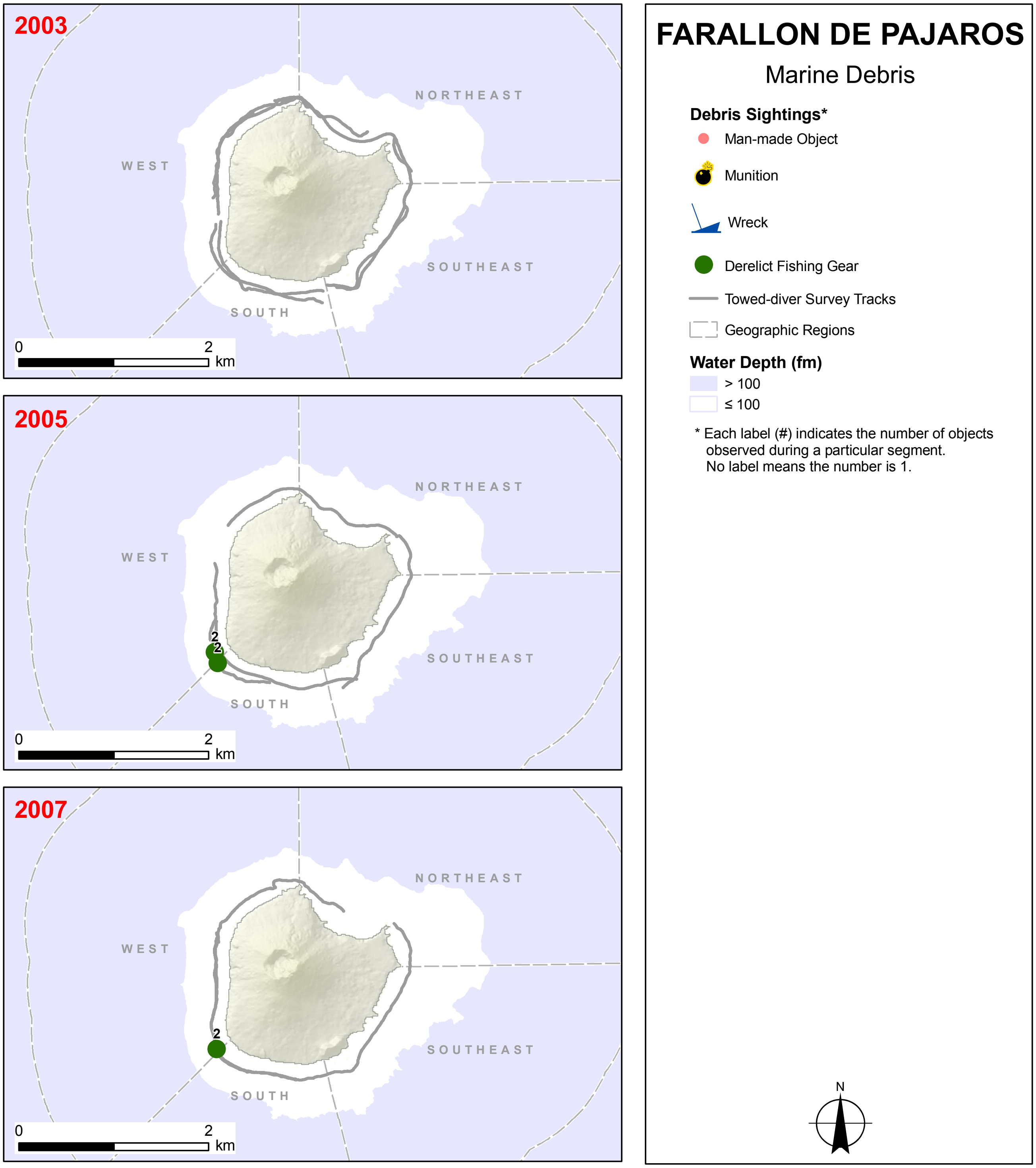


Figure 17.9.1a. Qualitative observations of marine debris from towed-diver benthic surveys of forereef habitats conducted around Farallon de Pajaros during MARAMP 2003, 2005, and 2007. No debris sightings were recorded in 2003. Symbols indicate the presence of specific debris types.

17.10 Ecosystem Integration

The spatial distributions and temporal patterns of individual coral reef ecosystem components around the island of Farallon de Pajaros are discussed in the discipline-specific sections of this chapter. In this section, key ecological and environmental aspects are considered concurrently to identify potential relationships between various ecosystem components. In addition to this island-level analysis, evaluations across the entire Mariana Archipelago are presented in Chapter 3: “Archipelagic Comparisons,” including archipelago-wide reef condition indices with ranks for Farallon de Pajaros as well as the other 13 islands covered in this report.

Farallon de Pajaros is an active volcano, and frequent eruptions during the 19th century affected both its landscape and seascape. The steep onshore slopes of Farallon de Pajaros continue underwater, forming steep submarine flanks. These flanks are incised by ridges that radiate out from depths < 30 m to depths of 400–600 m. High backscatter values were recorded on some of these ridges, suggesting that they may be characterized by hard substrate at or near the seabed surface. Between these ridges, low backscatter values indicate soft sediments accumulating in channels. Cold-water intrusions (26.1°C, which was 3.5°C colder than surface waters) originating from depths > 30 m were prominent around Farallon de Pajaros in 2007, likely because of upwelling or internal tide activity.

The variable topography and oceanographic conditions around Farallon de Pajaros provide a highly variable coral reef habitat. Overall, live-hard-coral cover on forereef habitats was low during the 3 MARAMP survey years, compared to observations at other islands in the Mariana Archipelago (Fig. 17.10a). Coral-colony density was highest for the smallest size class (0–5 cm) in each of the 3 survey years (Fig 17.10b), and densities increased from 2003 to 2005. Forereef habitats, as observed by towed divers, were generally loose boulders and rubble and are likely inhospitable environments for prolonged coral growth. Conditions are most extreme in the northeast, southeast, and south regions, where high wave energy causes regular overturning of the loose substrate (Fig 17.10c).

In the west region, forereef habitats of medium to medium-high complexity included boulders on sand and patches of rocky reef. This region is characterized by low ambient wave activity and medium episodic activity, suggesting that this area is relatively sheltered compared to the rest of this island. Estimates of coral cover from towed-diver surveys were consistently highest in this region, compared to the other 3 regions (Fig. 17.10a). In each of the 3 MARAMP survey years, mean large-fish biomass was highest in the west region, where sharks (Carcharhinidae and Ginglymostomatidae) and jacks (Carangidae) were common (Fig. 17.8a in Section 17.8: “Reef Fishes”). Similarly, REA benthic surveys conducted during the 3 MARAMP survey periods showed the highest total fish biomass in the west region.

The southeast and northeast regions of Farallon de Pajaros are characterized by high ambient wave energy. An STR deployed at a depth of 17 m in the southeast region recorded high-frequency (~ 12-h return periods) temperature fluctuations of 1°C–3°C during the springs of 2006 and 2007. Internal tides are generated when tidal currents interact with steep subsurface topography. High-frequency variability in temperature, dissolved nutrients, and suspended particle concentrations could be a result of internal tides carrying deeper water onto the shallow reef shelf in this area. In both the southeast and northeast regions, a narrow shelf is present at depths of 10–40 m. Towed divers observed sandy habitats of low complexity on this shelf. A second, larger shelf, which may be related to an older portion of this volcano, fans out from the northeastern point of this island and gently deepens from a depth of ~ 150 m to depths of 250–300 m.

In 2007, 3 REA sites on forereef habitats were surveyed for coral disease around Farallon de Pajaros, and no cases were detected. Farallon de Pajaros was the only island in the Mariana Archipelago to exhibit no coral disease. The lack of coral disease observed at Farallon de Pajaros could be a result of the generally low level of coral cover recorded.

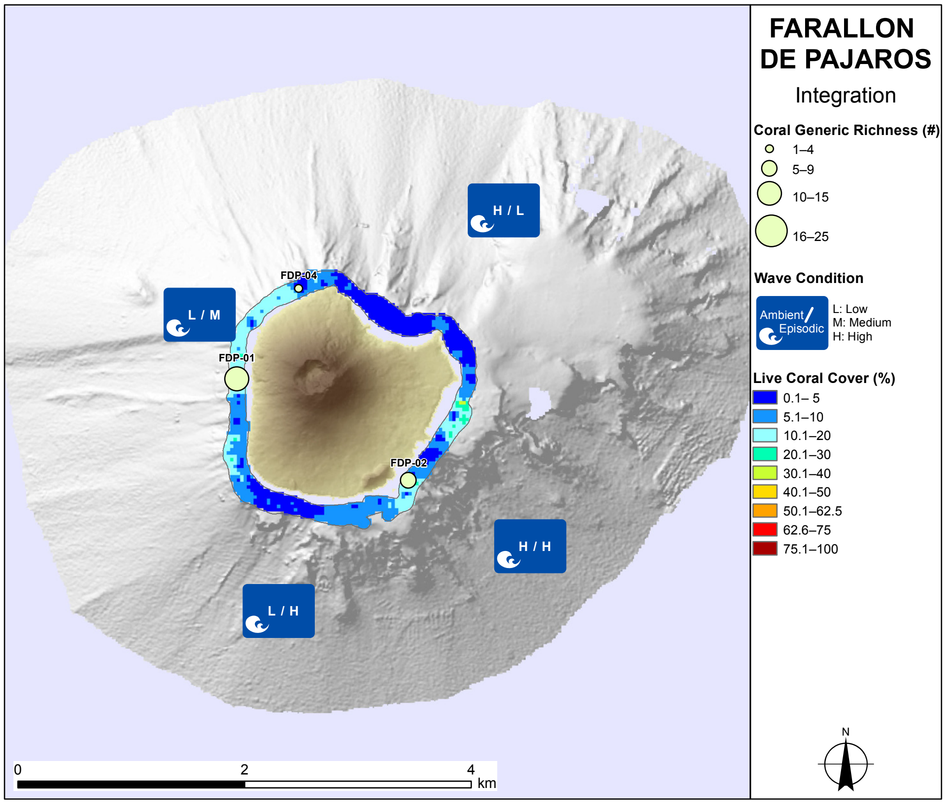


Figure 17.10a. Observations of cover (%) of live hard corals from towed-diver surveys and generic richness from REA surveys conducted on forereef habitats around Farallon de Pajaros during MARAMP 2003, 2005, and 2007. Values of coral cover represent interpolated values from the 3 MARAMP survey years, and values of coral generic richness represent averages of data from the 3 survey years. A large, blue icon indicates the level of ambient and episodic wave exposure for each geographic region.

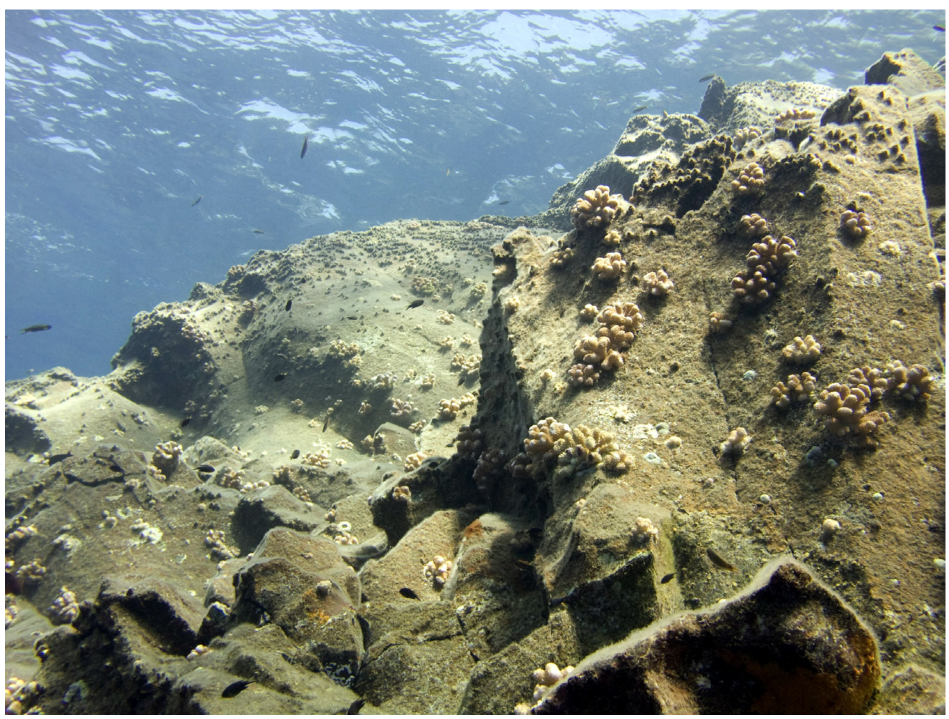


Figure 17.10b. Young coral recruits on the steep flanks of Farallon de Pajaros. *NOAA photo by Robert Schroeder*

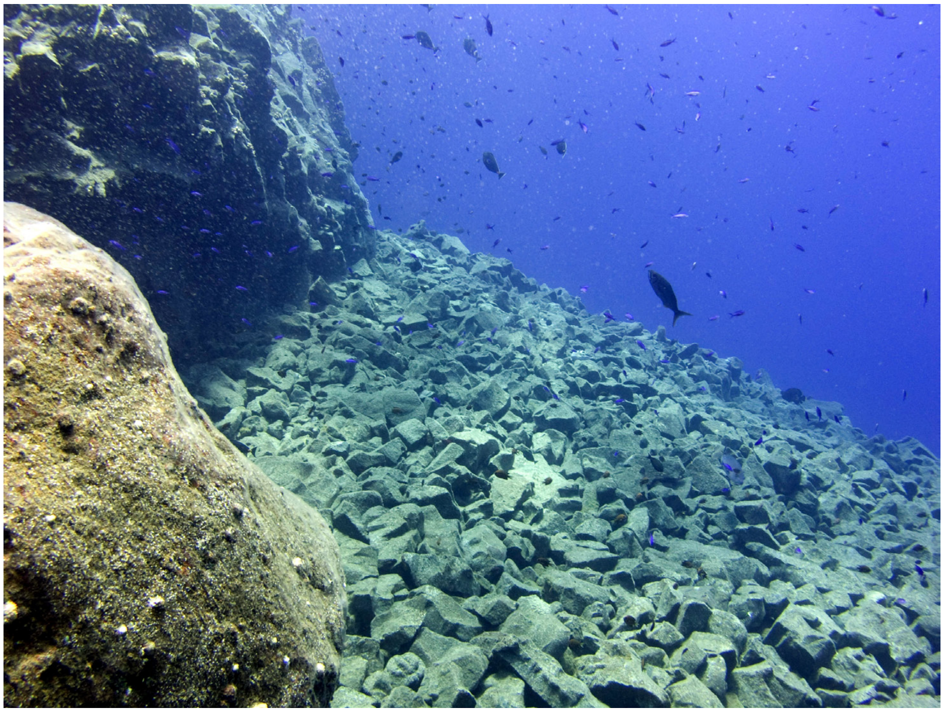


Figure 17.10c. Rocky terrain on most flanks of Farallon de Pajaros makes them inhospitable for coral growth. *NOAA photo by Robert Schroeder*

17.11 Summary

MARAMP integrated ecosystem observations provide a broad range of information: bathymetry and geomorphology, oceanography and water quality, and biological observations of corals, algae, fishes, and benthic macroinvertebrates along the forereef habitats around Farallon de Pajaros. Methodologies and their limitations are discussed in detail in Chapter 2: "Methods and Operational Background," and specific limitations of the data or analyses presented in this Farallon de Pajaros chapter are included in the appropriate discipline sections. Methods information and technique constraints should be considered when evaluating the usefulness and validity of the data and analyses in this chapter. The conditions of the fish and benthic communities and the overall ecosystem around Farallon de Pajaros, relative to all the other islands in the Mariana Archipelago, are discussed in Chapter 3: "Archipelagic Comparisons."

This section presents an overview of the status of coral reef ecosystems around the island of Farallon de Pajaros as well as some of the key natural processes and anthropogenic activities influencing these ecosystems:

- Farallon de Pajaros, which translates from Spanish to Isle of the Birds, is also known as Uracas. With a land area of 2.2 km^2, it is the second-smallest and most northerly island in the CNMI. This island is an active volcano, with only the top visible above sea level and a base that is 15–20 km in diameter. The rim of this volcano's still active crater is the highest point of this island with an elevation of 360 m.

- Farallon de Pajaros is a protected reserve under the CNMI Constitution, a status that prohibits inhabitation or building of permanent structures. This island, including its waters and submerged lands, is also included within the Islands Unit of the Marianas Trench Marine National Monument, which was established by presidential proclamation in January 2009.

- Farallon de Pajaros is surrounded by uniformly steep slopes that are incised by ridges that radiate out from this island from depths < 30 m to depths of 400–600 m. In the west and south regions, towed divers reported habitats of medium to medium-high complexity that included boulders on sand and patches of rocky reef. In the southeast and northeast regions, a narrow shelf is present at depths of 10–40 m. Towed divers observed sandy habitats of low complexity on this shelf.

- Wave model output shows high, ambient trade wind energy impacting the northeast and southeast exposures of this island. Episodic, long-period, high wave energy from storm-driven swells impact the south and southeast exposures and to a lesser extent the west.

- High-frequency (return periods of ~ 12 h) temperature fluctuations of 1°C–3°C were recorded in the springs 2006 and 2007. These temperature fluctuations could be an internal tide signal generated when tidal currents interact with steep subsurface topography and deep water is drawn upward onto the shallow reef.

- Mean cover of live hard corals was 3.6%, based on surveys at 3 REA sites in 2007. Islandwide mean coral cover from towed-diver surveys declined from 10% in 2003 to 5% in 2005 and 2007. These values are low compared to other survey areas in the Mariana Archipelago.

- In 2007, 3 REA sites at Farallon de Pajaros were surveyed for the occurrence of coral disease and predation, and no cases were detected. Farallon de Pajaros was the only island in the Mariana Archipelago to exhibit no coral disease, likely because of the low abundance of corals observed.

- Macroalgal cover from towed-diver surveys was slightly lower in 2007 than in 2005 for some areas surveyed, particularly for east-facing reefs. The overall occurrence of macroalgal genera recorded at REA sites did not fluctuate greatly between MARAMP 2003, 2005, and 2007.

- Cover of crustose coralline red algae increased by 5% from 2003 to 2005. The primary reason for this change was the observation of higher cover values along the east- and west-facing reefs in 2005 than in 2003. Overall mean cover fell from 8% in 2005 to 5% in 2007, and declines were observed particularly in surveys conducted in the east region. No cases of coralline-algal disease were registered.

- Large-fish biomass was relatively high at Farallon de Pajaros, compared to other survey areas in the Mariana Archipelago. In general, large-fish biomass was highest in the west region, where sharks (Carcharhinidae and Ginglymostomatidae) and jacks (Carangidae) were common. Sharks were especially common in 2003, when towed divers observed 82 individuals, versus the only 3 and 20 sharks seen in 2005 and 2007. Similarly, results from REA surveys of fishes of all sizes conducted during the 3 MARAMP survey periods show that the highest levels of fish biomass were recorded in the west region.

- Notable observations from towed-diver fish surveys included sightings of the rare giant grouper (*Epinephelus lanceolatus*) in 2003.

- No COTS or sea cucumbers were observed at Farallon de Pajaros, and densities of giant clams were extremely low during each of the 3 MARAMP survey years, compared to levels observed at other islands surveyed. Sea urchins were common in the southeast region.